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# FLOODPLAIN MAPPING USING SOIL SURVEY GEOGRAPHIC (SSURGO) DATABASE

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Phillip R. Owens

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# FLOODPLAIN MAPPING USING SOIL SURVEY GEOGRAPHIC (SSURGO) DATABASE

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Nikhil Sangwan

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*Dedicated to my family.*

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# ABSTRACT

Sangwan, Nikhil. M.S.C.E., Purdue University, May 2014. Floodplain mapping using Soil Survey Geographic (SSURGO) database. Major Professor: Venkatesh Merwade.

Floods are the most damaging of all natural disasters, adversely affecting millions of lives and causing financial losses worth billions of dollars every year across the globe. Flood inundation maps play a key role in assessment and mitigation of the potential flood hazards. However, there are several communities in the United States for which the flood risk maps have not been published yet, as the current flood inundation mapping methods are typically very expensive and time consuming. The objective of this study is to develop and examine an economical alternative approach to floodplain mapping using widely available soil survey data. In this study, floodplain maps were developed for the entire state of Indiana, and some counties in Washington, Minnesota, and Wisconsin by identifying the flood-prone soil map units based on their attributes recorded in the SSURGO database. For validation, the flood extents predicted by these maps were compared with the extents predicted by other floodplain maps viz.: Federal Emergency Management Agency (FEMA) issued Flood Insurance Rate Maps (FIRM), flood extents observed during past floods, and other floodmaps derived using Digital Elevation Models (DEMs). In general, SSURGO based floodplain maps were found to be largely in agreement with the other flood inundation maps. They were as effective as floodmaps

derived using DEMs in their predictions of flood extents. Although there was comparatively greater agreement between the FEMA maps and the observed flood extents, SSURGO floodplain maps could predict most of the observed flood extents with a median overlap of 72% between the two flood extents. Thus, albeit with a slight loss in accuracy, SSURGO approach offers an economical and fast alternative for floodplain mapping. In particular, it has potentially high utility in areas where no detailed flood studies have been conducted.

# CHAPTER 1. INTRODUCTION

Floods are the most devastating of all natural disasters, accounting for about one-third of the economic losses and over half of the deaths associated with natural disasters worldwide. According to Smith (2001), floods claim more than 20,000 lives per year and adversely affect about 75 million people world-wide, mostly through homelessness. Most recent examples of devastating floods in India (June 2013) and Pakistan (July 2010) directly impacting millions of lives indicate the ever increasing fury of this natural disaster. In the United States alone, where flood mitigation and prediction is relatively advanced, on an average, floods cause about $6 billion worth of damage and about 140 deaths every year (USGS, 2006). Federal Emergency Management Agency (FEMA) and several other disaster management agencies recognize that providing reliable information to the public about the risk associated with flooding plays a key role in mitigation of these losses (FEMA, 2001). Flood inundation mapping, which is defined as the process of delineating the area covered by water during a flood event on a map (Merwade et al., 2008), serves this purpose by informing the public and city planners about the flood prone areas in a region.

Currently, Flood Insurance Rate Maps (FIRMs) developed by FEMA under the National Flood Insurance Program (NFIP) are the most commonly used flood inundation maps in the United States. Typically, these FIRMs and several other flood inundation maps in current usage, correspond to 100-year return period stream flow values and are developed by a flood inundation modeling process which involves hydrologic modeling to estimate design peak flows from storm events in case of an ungauged basin, hydraulic modeling to estimate water surface elevations, and terrain analysis to estimate the inundation area (Anderson, 2000; Robayo et al., 2004; Knebl et al., 2005). Despite the recent advancements in the fields of hydrologic and hydraulic modeling and mapping tools, this approach has its own limitations. Uncertainty is inherent in the above approach, as there are inaccuracies involved at each step: in the design flow, terrain elevations, water surface elevations, and in various techniques used for mapping the inundation area (Merwade et al., 2008). Moreover, as noted by floodplain experts during the Gilbert F. White Flood Policy Forum (2004) which was convened to examine the usefulness of the 1% standard , the rationale behind the use of 100-year flood as standard does not have any scientific basis. The US Department of Housing and Urban Development chose 100-year flood as an official standard in 1968, as it found it a "good place to start from" in the absence of any economic feasibility study to determine a scientific standard (Gilbert F. White Flood Policy Forum, 2004). But above all, the major limitation of this approach is the huge amount of money and time involved in the process. According to FEMA (2007), "a riverine study typically costs $5000 to $10000 per mile of stream that is to be mapped, and hence, it is not cost effective to perform such a detailed study in watersheds where there is little or no development, such as in rural areas". Time and money is particularly on premium in developing countries, which makes the development of traditional flood inundation maps virtually unaffordable for these regions. Thus, there is a need for the development of an inexpensive, fast approach to flood inundation mapping, especially for less developed regions.

Wolman (1971) evaluated several alternative floodplain mapping techniques based on principles as diverse as physiography, pedology and vegetation, and noted that these techniques offer much cheaper and faster way to map flood-prone areas and give a precision that is adequate for rural, suburban, and recreational development. Physiographic approach is based on the historical relationship of floodplains with floods. Several studies have demonstrated that the floodplains are correlated to the unique flood frequencies on a number of rivers (Wolman, 1971). In another study, Cain & Beatty (1968) demonstrated that alluvial soils and soils with restricted drainage flood much more frequently than other soils. This strong correlation between soil characteristics and its flood-proneness forms the basis of the pedological approach to floodplain mapping. The application of these principles has become much easier and faster with the vast technological advancements that have been made in the field of data collection, remote sensing, cartography and information technology (especially Geographic Information System) in the last few decades The fact that the traditional approach, despite huge amounts of time and money invested in it, is still fraught with lots of uncertainties doesn't inspire much confidence among floodplain managers, and it further highlights the importance of alternative techniques that offer great savings in time and money for only a small relaxation of precision (Dunne & Leopold, 1978).

The objective of this study is to derive an economical and faster novel approach to floodplain mapping. To achieve this objective, floodplain maps were developed for the study areas by identifying flood-prone map units in the Soil Survey Geographic (SSURGO) database. To evaluate the performance of the proposed approach, the resulting floodplain extents were compared with the flood extents suggested by the standard FIRMs, observed flood extents, as well as other flood maps derived using the traditional approach.

# CHAPTER 2. STUDY AREA AND DATA

This chapter gives an overview of the study areas for which the soil based flood inundation maps were developed, the locations and streams where the validation studies were carried out, and the data that were used in the development and validation of these maps.

## 2.1 Study Area

Soil based flood inundation maps (SFMs) were developed for the entire Indiana state, as well as for certain select counties in the states of Washington, Minnesota, and Wisconsin (Figure 2.2). Indiana was chosen as the primary area of study for its long standing tryst with floods. Whether it is the Great Flood of 1913 that affected the entire Midwestern United States, or the Ohio River Valley flood in 1937, or the more recent June 2008 and April 2013 floods, Indiana has time and again faced the wrath of ravaging floods throughout its recorded history. Following sub-section gives an overview of the Indiana geography, and explains the causes or the conditions leading to Indiana's high susceptibility to severe flooding.

### 2.1.1 Primary study area: Indiana

Indiana with total area of 93,720 km$^2$ is located in the Midwest region of USA. It is predominantly an agricultural state with 57% of the total area being used for agricultural

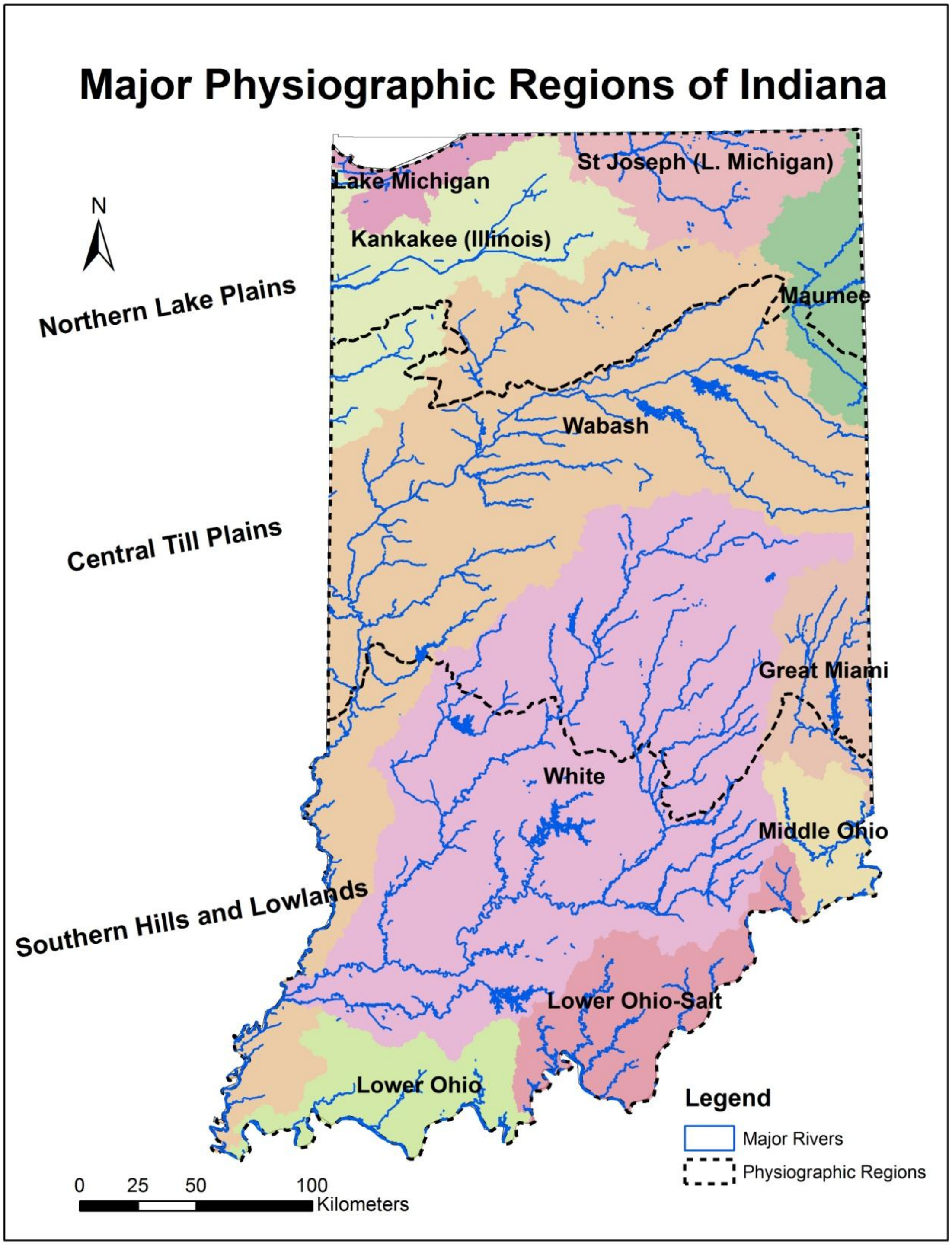


Figure 2.1: Major physiographic regions and river basins of Indiana

practices (NALCC, 2002; Kumar et al., 2009). Physiographically, Indiana is divided into three broad regions: the northern Great Lakes Plain , the central Tipton Till Plain in the centre, and the Southern Hills and Lowlands region (Schneider, 1966; Figure 2.1). Most of the state is drained by the Wabash River system. It drains around 62,160 $km^2$ of the area in Indiana. Other river basins are the Maumee in the extreme northeast, the St. Joseph (Lake Michigan) and Kankakee (Illinois River) in the north central and northwest, while some of the extreme south and southeast area drains into the Ohio River (Iclimate.org; NCDC, 1976). A dense network of rivers and tributaries makes the state naturally vulnerable to the surge in water levels due to any upstream storm events.

Indiana has a temperate and continental climate with daily air temperature ranging between -10°C to 4°C in January, and 21°C to 32°C in July. Precipitation varies from 14 cm to 110 cm of rainfall, and 50 cm to 250 cm of snow (Kumar et al., 2009). Although May is the wettest month of the year, the months of greatest flood frequency are from December through April. The primary cause of floods is prolonged periods of heavy rains, with rapid snow melt and frozen ground conditions also contributing to it (Iclimate.org; NCDC, 1976).

Majority of the Indiana state has a relatively flat topography (less than 2% slope) and poorly drained soils, resulting in frequent ponding (USDA, 2005). However, the northernmost counties have sandy soils, resulting in rapid drainage during rainy periods; thus, flooding is rarely a problem in the northern region.

### 2.1.2 Other Study Areas

For a wider geographical representation, the study area also includes certain regions of Washington, Wisconsin, and Minnesota states. SFMs were developed for four counties (viz. Lewis, Pierce, King, and Snohomish County) in western Washington, four counties (viz. Rice, Steele, Olmstead, and Goodhue County) in southern Minnesota, and five counties (viz. Vernon, Sauk, Rock, Jefferson, and Crawford County) in southern Wisconsin. These study areas are located in different physiographic regions, and have experienced major floods in recent times . More specifically, western Washington study areas are situated on the western slopes of Cascade Range, southern Minnesota is located in Central Plains, and southern Wisconsin counties are spread over Western Upland region and Eastern Ridges and Lowlands region (Figure 2.2).

## 2.2 Data

### 2.2.1 SSURGO database

The primary data used in this study is the SSURGO database, which was downloaded from the USDA (United States Department of Agriculture) web link http://websoilsurvey.sc.egov.usda.gov/ for the study areas mentioned in the previous subsection. SSURGO is the most detailed soil geographic database of the United States, and, as of date, it covers up around 95% of the counties, and provides an extensive amount of information about the soils in a soil survey region. It was the only data that was used in the derivation of SSURGO based floodplain maps (SFM). All the other data, mentioned in following paragraphs, were used in the validation of soil survey based

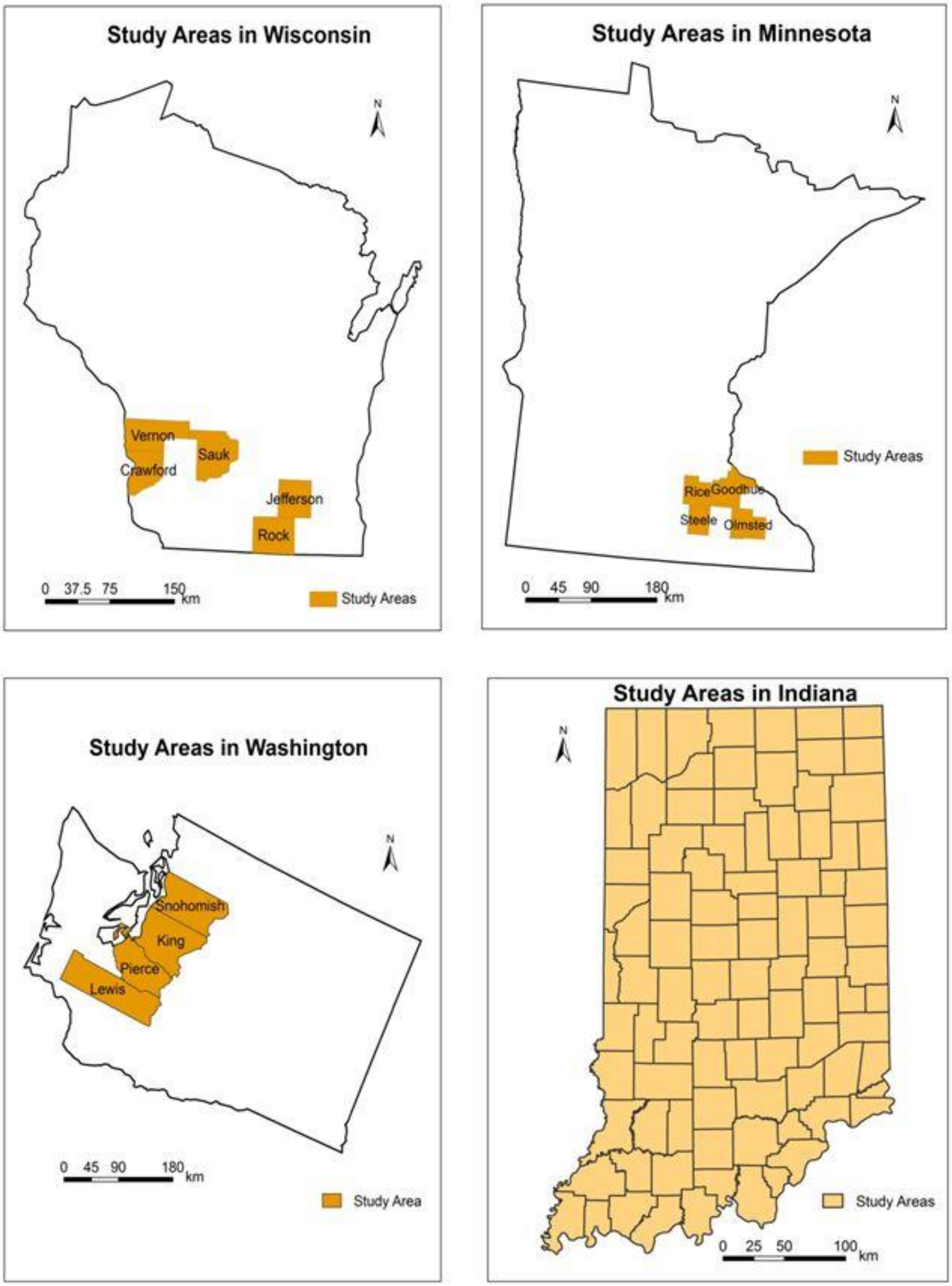


Figure 2.2 : Study Areas

floodplain maps. A more detailed description of SSURGO database has been separately provided in the Chapter 3.

### 2.2.2 Digital Flood Insurance Rate Maps (DFIRMs)

National Flood Insurance Act of 1968 requires FEMA to identify all flood-prone areas in the United States and establish flood-risk zones within the flood-prone areas. To attain this objective, first the approximate studies were carried out by FEMA to delineate the Flood Hazard Boundary Maps (FEMA, 2006). Later, more detailed studies were done to publish the Flood Insurance Study (FIS) reports and Flood Insurance Rate Maps (FIRMs) for developed or fast-developing communities. The process of these detailed studies involved (a) measurement (discharge gages) or estimation (regression analysis or hydraulic modeling) of stream flows, (b) getting the cross-sectional geometry at regular spacing along streams from ground surveys, aerial photography, or topographic maps, (c) hydraulic modeling to determine the flood elevations, velocities and floodplain widths at each cross-section for different frequency floods (viz. 10, 50, 100 and 500 year floods), (d) determining the flood profile by interpolating the water surface elevations between each cross-section, and (e) transferring the flood profile on to a base map.

A flood insurance rate map (Figure 2.3) essentially consists of floodway boundaries and flood insurance zone designations (FEMA, 2006). Note that Zones starting with letters A or V represent the areas which are likely to be inundated in a 100-year flood scenario; Shaded Zone X represents 500-year floodplains, areas with less than 1-feet of water inundation depth in case of a 100-year flood, and areas protected by levees from 100-year flood; Unshaded Zone X is the area lying outside 500-year floodplain, and Zone D is the zone of areas where flood hazards were not determined. These countywise FIRMs were finally digitized to get the digital maps i.e. DFIRMs.

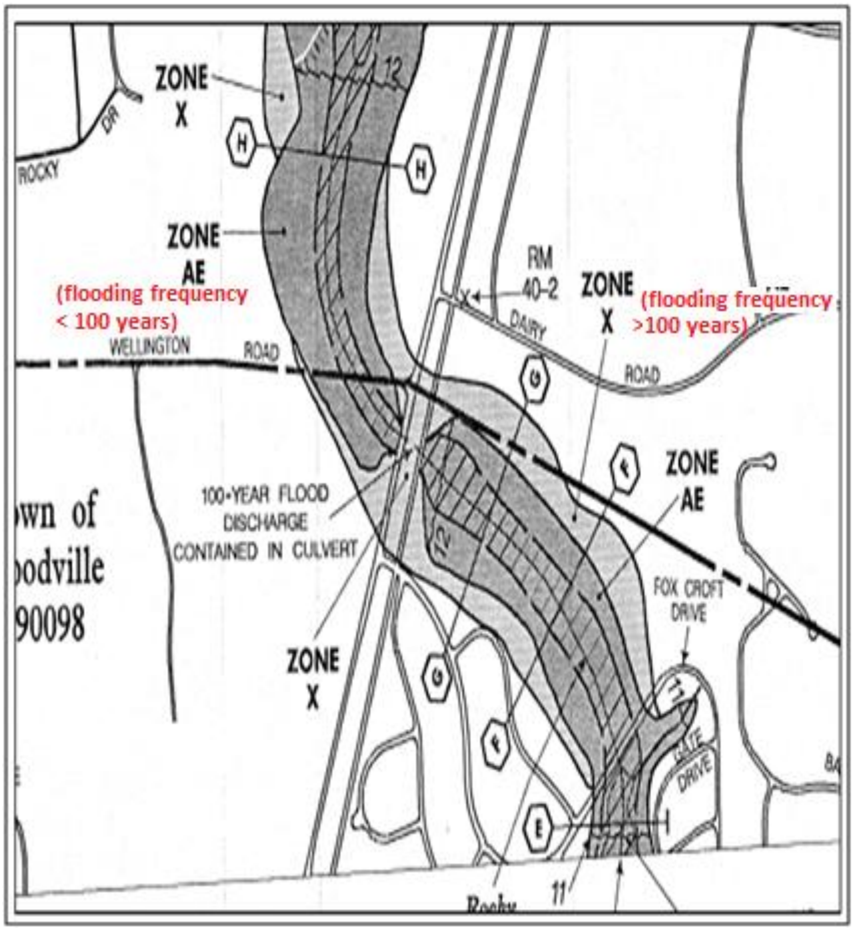


Figure 2.3: Different zones in a Flood Insurance Rate Map (adapted from FEMA, 2006)

DFIRMs for select few counties in Indiana (viz. Allen, Marion, Johnson, Lake, Miami, Lawrence, Putnam) and Wisconsin (viz. Sauk, Rock, Vernon, Jefferson, Crawford) were bought from FEMA's Map Service Center (https://msc.fema.gov/). DFIRMs for all the other counties were downloaded from the respective state department of natural resources or ecology website. Specifically, Indiana DFIRMs were downloaded from the Indiana

Department of Natural Resources web link http://www.in.gov/dnr/water/3484.htm; Minnesota DFIRMs were downloaded from its Department of Natural Resources website http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/fema_firms.html; and Washington DFIRMs were downloaded from the Washington Department of Ecology website http://www.ecy.wa.gov/services/gis/data/flood/flood.htm. Each of these file packages contains a shapefile named *S_Fld_Haz_Ar,* from which special flood hazard zones, i.e. areas with more than 1% likelihood of getting flooded in any given year, were delineated by selecting the zones starting with letter A or V. These 1% flood insurance rate maps have been referred as FIRMs in this study.

Note that the one-percent annual chance flood was officially chosen as the standard for flood risk management in the US with the passage of the National Flood Insurance Act in 1968. According to FEMA's instructional material on flood studies and maps (FEMA, 2006) , the choice was made as "a compromise between a more frequent flood (such as a 10-percent chance flood), which would permit excessive exposure to flood risk, and a more infrequent flood (say, a 0.1-percent chance flood), which would be considered as excessive and unreasonable standard." Although the one-percent standard continues to be in use till-date, time and again questions have been raised against its efficacy and grounds of origin (Glibert F White national flood policy forum, 2004). Even otherwise, the uncertainties (associated with several stages of its methodology) in the flood extent predictions by FEMA maps cannot be denied, and thus DFIRMs are far from being totally trustworthy.

### 2.2.3 Observed flood extents

Recent floods in the four states viz. Indiana, Washington, Minnesota, and Wisconsin were considered for the validation of the SFMs. The flood extents of these floods were extracted from various United States Geological Survey (USGS) investigation reports (Table 2.1). Barring the Washington state, the geo-referenced flood extents for the study regions were available as appendices to the USGS reports. For Washington, first the Point Z shapefile(s) were created from the known high water mark (HWM) co-ordinates and elevation, and then these HWM points were used to geo-reference the flood extent imageries for each study area.

USGS used a very elaborate process to estimate the flood extents in these study areas. First, the location and elevation of HWMs were recorded in the field. Then, the water-surface elevations along a stream segment were interpolated from these HWM elevations using a GIS program, followed by addition of cross-sections (lines of equal, potential peak water-surface elevation) perpendicular to the flow direction. Next, the point coverage of surface elevations along a stream segment were interpolated from these HWM elevations using a program, followed by addition of cross-sections (lines of equal, potential peak water-surface elevation) perpendicular to the flow direction.

Thereafter, the point coverage of these cross-sections was used to generate a surface with a Triangular Irregular Network (TIN) interpolator. Finally, using flood-mapper AML (Arc Macro Language scripts), DEM was subtracted from this water-surface elevation TIN to get the flood inundation extent and depth grids. Apart from the HWM survey,

Table 2.1: Recently observed floods in the study areas

| State | Stream | Location | Time of flood | USGS Report Ref. |
|---|---|---|---|---|
| IN | White River | Martinsville | Jun, 2008 | Morlock et al. (2008) |
| | White River | Seymor | | |
| | White River | Spencer | | |
| | White River | Worthington | | |
| | White River | Paragon | | |
| | White River | Columbus | | |
| | White River | Haw | | |
| | White River | Newberry | | |
| | Blue River | Edinburgh | | |
| | Blue River | Swale | | |
| | Clifty Creek | Columbus | | |
| | Hurricane Creek | Franklin | | |
| | Canary Ditch | Franklin | | |
| | Youngs Creek | Franklin | | |
| | Eel River | Worthington | Sep, 2008 | Fowler et al. (2010) |
| | Little Calumet | Hammond | | |
| | Deep River | Hobart | | |
| | Turkey Creek | Schererville | | |
| | White Ditch | Michiana Shores | | |
| WA | Cedar River | Renton | Jan, 2009 | Mastin et al. (2010) |
| | Newaukum River | Chehalis | | |
| | Puyallup River | Orting | | |
| | South Prairie Creek | South Prairie | | |
| | Stillaguamish River | Arlington | | |
| | Snoq Tolt River | Carnation | | |
| | Snoqualmie River | Snoqualmie | | |
| MN | Straight River, Cannon River | Faribault | Sep, 2010 | Ellison et al. (2010) |
| | Straight River, Maple Creek | Owatonna | | |
| | North Branch, Middle Fork | PineIsland | | |
| | Zumbro River | Zumbro Falls | | |
| WI | Rock River | Beloit | Jun, 2008 | Fitzpatrick et al. (2008) |
| | Rock River | Janesville | | |
| | Rock River, L. Koshkonong | Fort Atkinson | | |
| | Kickapoo River | Gaysmills | | |
| | Kickapoo River | Lafarge | | |

other reliable sources of information such as peak-gage height(s) recorded by the streamgage (if available), aerial photographs of the flood extents, accounts by local people were also taken into consideration for the generation of the water-surface (Morlock et. al, 2008; Mastin et. al, 2010; Ellison et. al, 2010; Fitzpatrick et. al, 2008) . Thus, the flood extents suggested by these USGS reports resemble the actual flood extents observed during these floods with a reasonable accuracy.

### 2.2.4 Digital Elevation Models (DEMs)

The performance of SFMs was also compared with that of 100-year flood maps derived from DEMs. For this purpose, 30 m and 10 m resolution National Elevation Dataset (NED) DEMs were downloaded from the United States Geological Survey (USGS) database (http://viewer.nationalmap.gov/) for the study areas in Indiana. NED is a combination of elevation data obtained from various sources such as USGS quadrangle maps, active remote sensing technologies like LIDAR, and digital photogrammetric processes (Sanders, 2007).

### 2.2.5 Stream stage and discharge data

One-percent annual chance water surface elevations needed for the derivation of above mentioned DEM based flood inundation maps (DFMs) were calculated from the stage and discharge records maintained by the Ohio River Forecast Center (OHRFC) and the USGS along several streams in Indiana.

The historical daily stage data (1950-1997) observed at several OHRFC stations (Figure 2.3, Table 4.2) on the major streams in Indiana were obtained from OHRFC in a Extensible Markup Language (xml) format.

The validation study was also carried out along lower order creeks located in different geographic regions of Indiana (Figure 2.4, Table 2.2). The 100-year return period peak flow for each of these creeks was calculated from the annual peak flow value records maintained by USGS (http://waterdata.usgs.gov) along these streams.

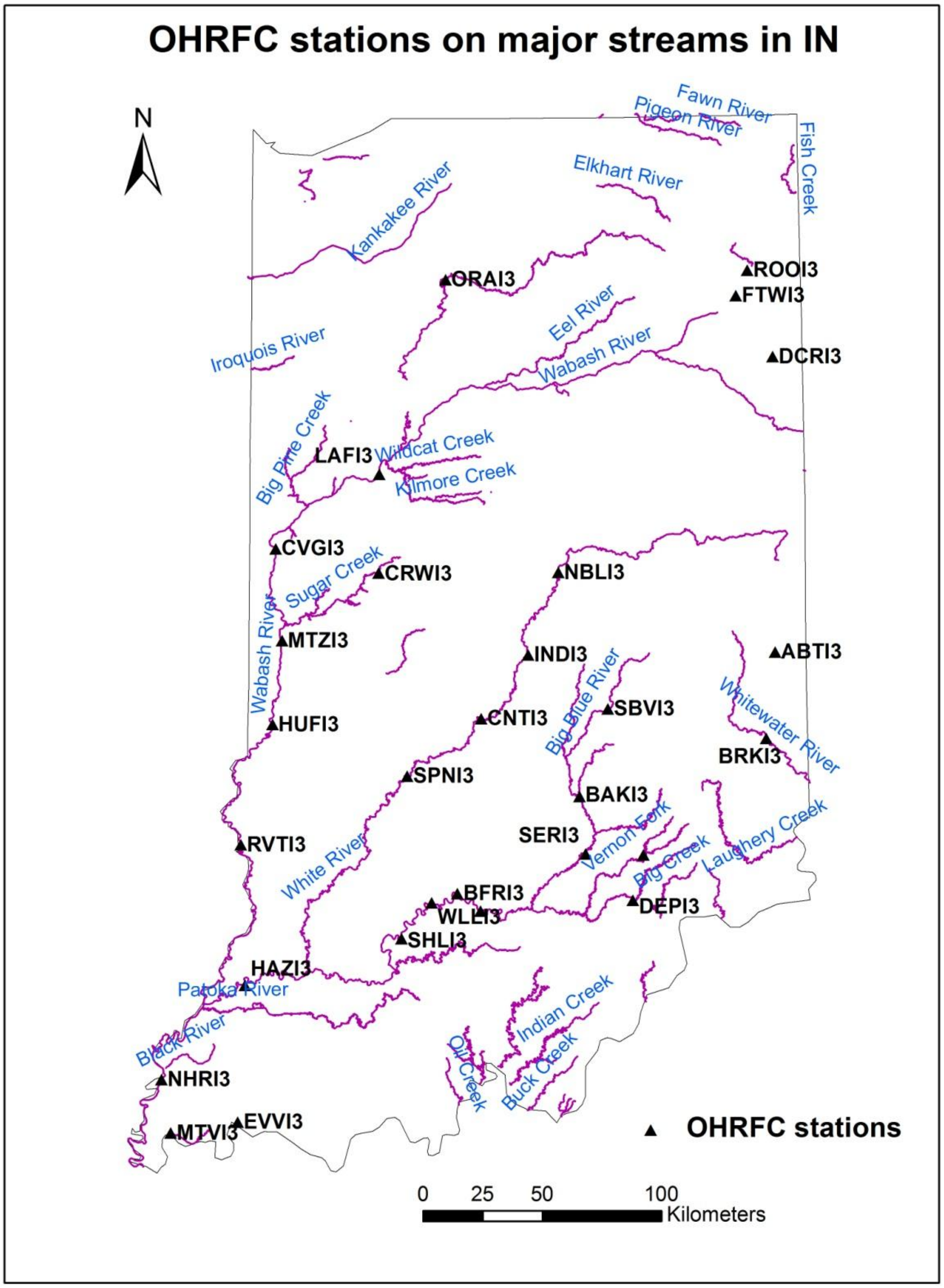


Figure 2.4 : OHRFC stations on major streams in Indiana study area

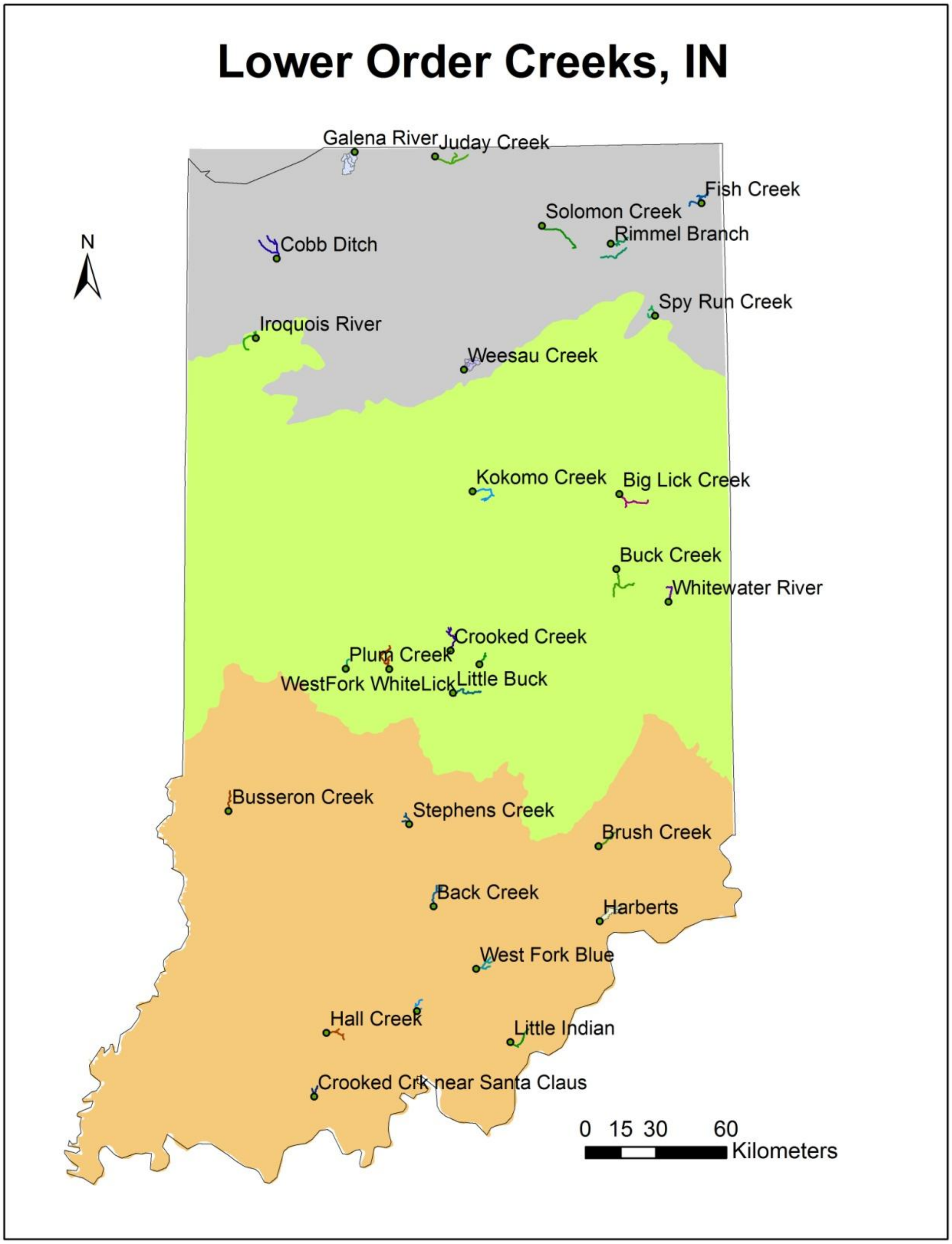


Figure 2.5 : Lower Order Creeks in Indiana relevant to the validation study

Table 2.2 : Lower Order Creeks in Indiana, and the corresponding USGS stations

| S No | Lower Order Streams | IN Region | USGS gage | 100-year return period discharge, cfs |
|---|---|---|---|---|
| 1 | Cobb Ditch near Kouts | Northern Lake Plains | 05517890 | 1366 |
| 2 | Fish Creek at Hamilton | | 04177720 | 1295 |
| 3 | Galnea River near Laporte | | 04096100 | 1125 |
| 4 | Iroquois River at Rosebud | | 05521000 | 652 |
| 5 | Juday Creek near South Bend | | 04101370 | 308 |
| 6 | Rimmell Branch near Albion | | 04100295 | 55 |
| 7 | Solomon Creek near Syracuse | | 04100377 | 450 |
| 8 | Spy Run Creek at Fort Wayne | | 04182810 | 1527 |
| 9 | Weesau Creek near Deedsville | | 03328430 | 640 |
| 10 | Big Lick Ceek near Hartford City | Central Till Plains | 03326070 | 2300 |
| 11 | Buck Creek near Muncie | | 03347500 | 2068 |
| 12 | Crooked Creek at Indianapolis | | 03351310 | 4942 |
| 13 | Kokomo Creek near Kokomo | | 03333600 | 1410 |
| 14 | Little Buck Creek near Indianapolis | | 03353637 | 3640 |
| 15 | Pleasant Run at Arlington | | 03353120 | 2674 |
| 16 | Plum Creek near Bainbridge | | 03357350 | 1202 |
| 17 | Westfork Whitelick Creek at Danville | | 03353700 | 9838 |
| 18 | Whitewater River near Economy | | 03274650 | 1398 |
| 19 | Back Creek at Leesville | Southern Hills and Lowlands | 03371520 | 16440 |
| 20 | Brush Creek near Nebraska | | 03368000 | 8390 |
| 21 | Busseron Creek near Hymera | | 03342100 | 2152 |
| 22 | Crooked Creek near Santa claus | | 03303400 | 5633 |
| 23 | Hall Creek near St. Anthony | | 03375800 | 10252 |
| 24 | Harberts Creek near Madison | | 03366200 | 2307 |
| 25 | Little Indian Creek near Galena | | 03302300 | 7386 |
| 26 | Patoka River near Hardinsburg | | 03374455 | 5988 |
| 27 | Stephens Creek near Bloomington | | 03372300 | 6556 |
| 28 | Westfork Blue River at Salem | | 03302680 | 7513 |

# CHAPTER 3. SOIL SURVEY GEOGRAPHIC DATABASE

This chapter briefly describes SSURGO database and its basic structure.

## 3.1 Soil Surveys

A soil survey describes the characteristics of the soils in a given area, classifies and maps them, and records other information and predictions related to them (Soil Survey Staff, 1993). NRCS has compiled three digital soil geographic databases viz. NATSGO, STATSGO, and SSURGO, each representing different scales of soil mapping (Figure 3.1; adapted from Lin, 2003). SSURGO is the most detailed database, for which the most of

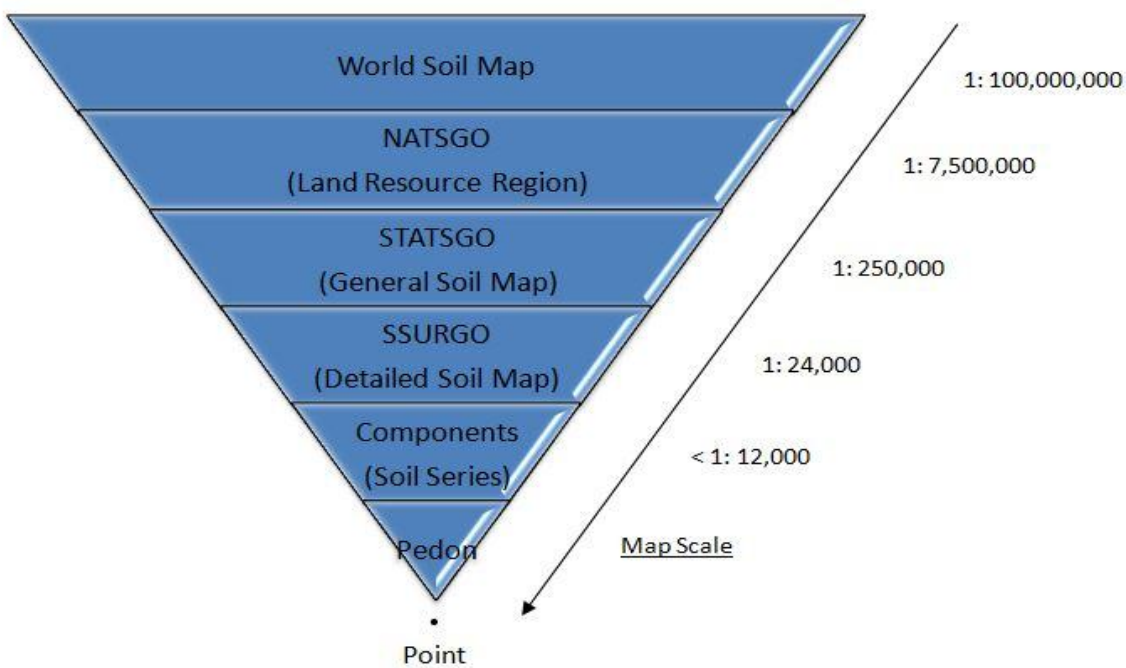


Figure 3.1 : Soil survey hierarchy

the information was collected at a scale of 1:12,000 to 1:24,000 over the course of a century (NRCS, n.d.). The information collection process involved field observations as well as certain laboratory tests. Soil scientists recorded the characteristics of the soil profiles that they studied during the process, and then classified the soils in a survey area based on their major characteristics and the arrangement of horizons within the profile (Soil Survey Staff, 1993). The recorded information was not just limited to the defining characteristics like color, texture, aggregate sizes, distribution of plant roots etc., but also included observations like land slope, kinds of bed rock, natural vegetation and flooding frequency of the area, and many other predictions based on such observations (Soil Survey Staff, 1993).

## 3.2 Map Units

The basic building blocks of a soil survey map are its closed polygons termed as map units (Figure 3.3). A map unit is a collection of areas grouped together in terms of their soil components or miscellaneous areas or both. In general, a map unit is named after its dominant component. More specifically, its name is derived from the taxon lowest in hierarchy that accurately identifies the dominant soil component, and very often includes phase description as well (Soil Survey Staff, 1993). Soil series, which consists of pedons having horizons that are similar in soil color, texture, soil structure, composition, and arrangement in the soil profile, is the most specific taxon level in the USDA soil taxonomy tree (Figure 3.2), and thus forms the basis for the nomenclature of the most map units. Soil series, in turn, are commonly named after the towns where they were first studied (USDA NRCS,1999).

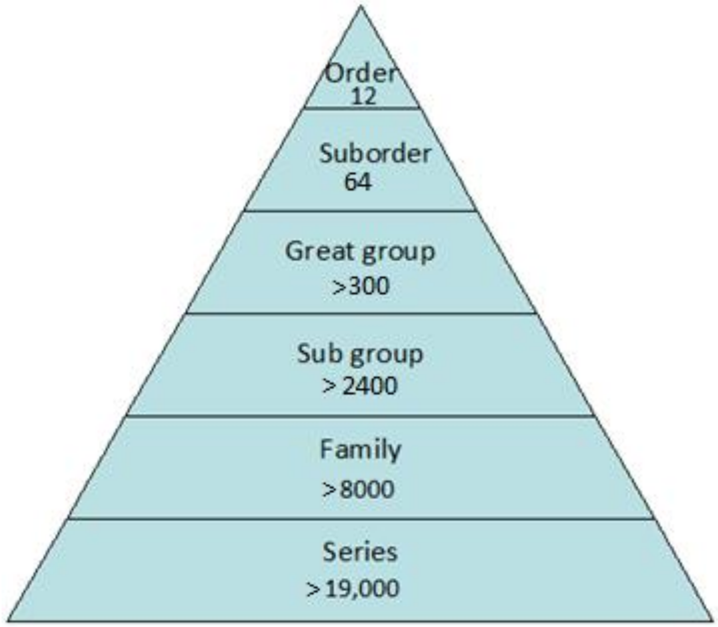


Figure 3.2 : USDA Soil Taxonomy categories

For example: Map units with name *Ba* represents the areas with soil majorly belonging to the *Bartle silt loam* soil series; *BdA and BdB* represent areas with Bedford silt loam at 0-2% and 2-6% slope respectively. Certain areas have essentially no soil and support little or no vegetation for various reasons. Map units associated with such areas, also termed as miscellaneous areas, are named after their distinguishing features. For example, *Water* is the map unit name for the areas covered with water bodies. Note that these map units may have some inclusions of soil (less than 15% ) and other miscellaneous areas (less than 25%) which are not significant enough. In case the amount of soil exceeds the standards for inclusions, the map unit is termed as a complex or association of miscellaneous area and soil (Soil Survey Staff, 1993).

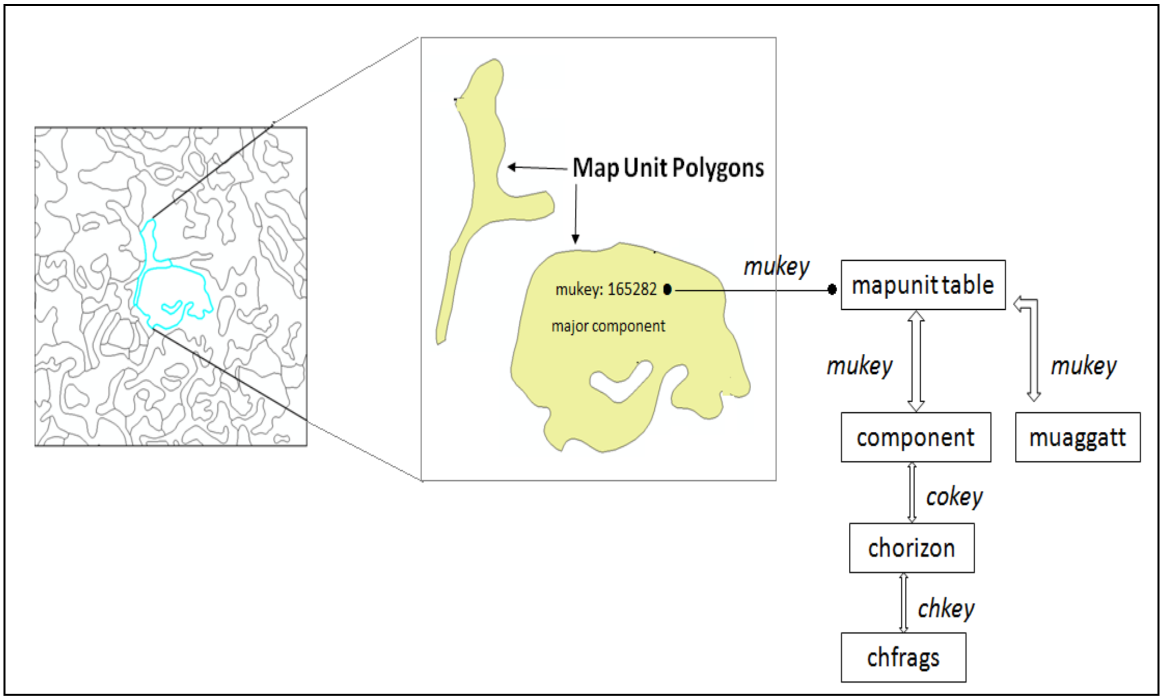


Figure 3.3 : Structural relationship between map units and tabular data in SSURGO

## 3.3 Tabular data

The extensive amount of information related to the soils in a survey area, gathered and interpreted by the soil scientists, has been organized and presented in the form of tabular data by NRCS. There are approximately 60 tables containing in total, perhaps, more than a thousand attribute columns. How does one work with such an extensive data, and more importantly how does one map so much information to its geographical origin? Figure 3.3 provides a schematic to understand different SSURGO elements and their associations with each other. The tabular data can be broadly divided into three categories.

First category of tables have their names starting with *mu,* and the entries in these tables can be directly linked to their specific map units in the map unit shapefile (map unit attribute table to be more specific) using *mukey* as the key identifier. Some of the examples of tables in this category are muaggatt, mucroyld, mutext. *Muaggatt,* short for map unit aggregated attribute, deserves a special mention as it records a variety of soil attributes (such as map unit name, flooding frequency, hydrologic group, slope gradient etc) that have been aggregated from the component level to a single representative value at the map unit level.

The names of the tables in secondary category begin with *co* prefix. These tables contain attributes of the soil components (subset of map units) that can be linked to their respective components in *component* table using *cokey* as the linking key. *Component* table plays a central role in the eventual mapping of these attributes to their respective map units as it has both the bridging keys viz. cokey and mukey. To link an attribute in cocropyld to its map unit, for instance, one would first link it to its corresponding component in the component table using cokey, and then link this component to the respective map unit in the main attribute table using mukey as the identifier. Apart from this central bridge role, *component* table lists the map unit components and their several properties (such as major component; low, high and representative elevation, slope; geomorphic description; soil taxonomy classes etc.). Cocropyld, coecoclass, cosoiltemp, copm are the other examples of tables from this category.

Third category of tables, beginning with *ch*, contain attributes of individual horizons. Attributes of a horizon in these tables can be linked to the respective horizon in *chorizon* table using *chkey,* which in turn can be linked to its respective component in the component table using cokey. Thus, component table and chorizon table together plays the bridging role between map units, components and horizons. chfrags, chtexturegrp are some other examples of tables from this category.

# CHAPTER 4. METHODOLOGY

## 4.1 Methodology Overview

This research study is based on the premise that SSURGO database which is available online free-of-cost for almost the entire country has the potential to provide an economical alternative approach for floodplain delineation. In order to attain the research objectives, a methodology was developed in which the floodplains were delineated for the study areas by selecting the SSURGO map units with attributes identifiable with their flood-proneness, and then these resulting maps were validated by comparing their delineation extents with the extents of other flood maps that are currently used by floodplain managers. These reference base maps were chosen such that they represented the regulatory standard (FEMA issued FIRMs), the actual flood scenarios (inundation extents observed during recent flood events), as well as the less sophisticated methods (flood maps derived using DEMs). To sum up, the methodology involved: (1) devising an approach to floodplain mapping using SSURGO database; (2) derivation of DEM based flood inundation maps using stages from OHRFC historical records; (3) derivation of DEM based flood inundation maps along lower order creeks using streamflow data and hydraulic modeling; and (4) comparison of the SSURGO based floodplain maps (SFM) with the other flood maps viz. standard FIRMs, observed flood extents, and the DEM based flood maps (DFMs) derived in steps 2 and 3.

## 4.2 Floodplain mapping using SSURGO database

SSURGO database was downloaded from the USDA website http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm for the study areas. A downloaded SSURGO dataset typically consists of digital georeferenced spatial data (maps) and tabular data corresponding to the selected survey area (or area of interest). Spatial data essentially consists of six shapefiles; only the shapefile (soilmu_a_ssxxx) containing the map unit boundary polygons is relevant to the study and was hence imported into an ArcGIS geodatabase. Note that all the geoprocessing involved in the derivation of soil survey based floodplain maps (SFMs) was carried out on these shapefiles using ArcGIS 10.0. Further, the tabular dataset is provided as a collection of ASCII delimited files. Each of these files represent a table, and can be read properly in a MS Access format. Thus, the tabular data were imported to the 2003 MS Access SSURGO template provided with the downloaded SSURGO data. These tables were then finally exported into the geodatabase containing the map unit shapefile.

As mentioned earlier, each map unit in the spatial data can be directly or indirectly linked to its corresponding attribute in the attribute tables using certain key identifiers like mukey or cokey. Using these key links, one can trace numerous attributes of a map unit, or conversely, identify the map units satisfying a conditional data query on their attributes. For this study, the latter approach was followed, and the areas (map units) most susceptible to flooding were identified by selecting the attributes linked to flood inundation phenomenon. The key thing here was to identify an appropriate set of such physical attributes.

### 4.2.1 Water bodies

Water bodies or land surfaces covered with water for most part of the year form an obvious inclusion for any flood risk map delineation. Thus, all those miscellaneous area map units which have their *muname = water* in the *muaggatt* table were selected. Note that according to soil survey manual (1993), SSURGO assigns muname=water to those map units that are "covered with water atleast during the period enough for plants to grow; it also includes pits, blowouts, and playas that contain water most of the time".

### 4.2.2 Flood frequency

Another useful attribute available in the *muaggatt* table is the flood frequency class given for each map unit. According to SSURGO 2.2.6 metadata (2012), *floodfreqdcd* (short for flood frequency - dominant condition) column in this table gives the "dominant flood frequency class for the map unit, based on composition percentage of map unit components whose composition in the map unit is equal to or exceeds 15%." Various flood frequency classes used for this purpose and their definition have been enlisted in the Table 4.1. This forms the second criterion for the target approach i.e. select map units with *flood frequency class* falling into either of *Rare, Occasional, Frequent* or *Very frequent* flood frequency class. Note that such a selection would correspond to all the areas with an annual chance of flood occurrence greater or equal to 1% . As a word of caution, however, it is worthwhile mentioning here that the wide range of flood frequencies used to define these classes do not indicate a high degree of accuracy, as the frequencies used to define classes were generally estimated from the evidences related to the soil and vegetation information gathered during the soil survey fieldwork (NRCS, n.d.). In fact, NRCS prefers traditional hydrological studies over these evidence based methods for a more precise evaluation of flood-prone areas along the streams. The evidence based approach employs various of sources of information like reports of various agencies, recollection by locals, landscape features resulting from past flooding, vegetation that grows in flood areas, high water marks, laboratory analysis of soil layers, etc. for the estimation of flood frequency class of a map unit (NRCS, n.d.).

Table 4.1: Map unit flood frequency classes and their definitions

| **Flood Frequency Class** | **Defining range of return period of floods** |
|---|---|
| None | Less than or equal to 500 years |
| Very Rare | 100-500 years |
| Rare | 20-100 years |
| Occasional | 2-20 years |
| Frequent | < 2 years; But less than 50% chance of flooding in all months in any year |
| Very Frequent | > 50% chance of flooding in all months in any year |

(*adapted from NRCS Technical Handbook, Part 618* )

A selection of map units with either muname equal to water or flood frequency greater than or equal to one percent would in itself essentially amount to the flood-prone area delineation for a region. However, for all the uncertainties or inaccuracies (inherent or otherwise) associated with this pair of selection, two more selection criteria were introduced to provide an extra factor of safety to the approach. These two criteria viz. *fluvial-origin soils* and *floodplains geomorphology* are respectively based on the pedological and physiographic approach mentioned earlier in the Introduction section.

### 4.2.3 Soil Taxonomy

The taxonomy description of a soil conveys a lot of information about the soil. USDA soil taxonomy establish hierarchy of classes (Figure 3.2) to facilitate better understanding of relationship among soils and the causative factors behind their characteristics (USDA NRCS, 1999). Soil genesis plays a fundamental role in this soil taxonomy. The top four levels in the hierarchy (viz. order, suborder, great group, subgroup) of this taxonomy are identified by the presence or absence of diagnostic horizons and characteristics (USDA NRCS, 1999). Soils of interest to this study, fluvial-origin soils, can be identified by restricting the selection search to taxa in just these four categories. In fact, the search was carried out at the subgroup category level only, as the nomenclature of soil taxonomy is such that the name of each taxon, with the exception of soil series, indicates its class in all categories of which it is a member. For instance, the name *Fluventic Aquicambids* conveys that the soil belongs to Aridisols Order (identifier: _*ids*), Cambids Suborder ( _*cambids*), Great Group ( _ *Aquicamibds*) and Fluventic Subgroup (*Fluventic*_).

The main task associated with the pedological approach is to look for soils that were formed by water-deposited sediments, or to be more precise, soils that have their genesis in the floods. It is assumed here that the presence of such soils in a region is a credible evidence of flooding in the past there. Soils belonging to the Fluvents suborder constitute an overwhelmingly large proportion of such soils. Fluvents are soils that were recently formed on floodplains, fans, and deltas along streams by the erosion and deposition actions of moving water (USDA NRCS, 1999). These are frequently flooded, and the age of fluvial sediments commonly range from a few years to a few hundred years (lower in case of humid regions) (USDA NRCS, 1999).

However, fluvents are not the only soils that are found on floodplains or indicates past flooding in a region. Consider, for instance, soils belonging to the great group fluvaquents. Fluvaquents are the stratified, wet soils found on floodplains and deltas. The sediments are of Holocene age, and are extensively found along large rivers, particularly in humid areas (USDA NRCS, 1999). These are grouped under aquent suborder and not fluvents, as they have the soil moisture regime of aquents; in other words, they are wetter Entisols with continuous or periodic saturation.

Although majority of the fluvial origin soils belong to the Entisol Order, which is characterized by the dominance of mineral soil materials and the absence of distinct pedogenic horizons, there are certain soils from other orders as well that can be associated with floodplains. Fluventic Dystrudepts, for instance, are soils of the Inceptisol Order that are found on floodplains along rivers draining regions that have acidic soils. These were formed in Holocene or recent alluvium, and are subject to occasional flooding (USDA NRCS, 1999).

There are numerous other such soils, from all across the taxonomy spectrum, that have history of floods associated with them. Fortunately, most of them can be identified by the presence of the formative element '*fluv*' (meaning: water-deposited) in the names of either of the four highest taxonomy levels. Since *taxsubgrp* column in the *component* table of

SSURGO contains the taxonomy information (subgroup, great group, suborder, order) for the major soil component of each map unit, most of the flood-prone areas can be delineated by selecting the map units containing the characters '*fluv*' in their *taxsubgrp* attribute field.

#### 4.2.4 Geomorphic Description

Apart from playing a key role in the soil genesis, flowing water is also accountable for shaping the geomorphology of a region. Physiographic approach is based on this strong relationship between the regional geomorphology and its hydrology. Geomorphic description of a map unit helps in the identification of a discrete land surface feature or assemblage of features in an area (Schoeneberger & Wyoscki, 2012).

In general, land features are results of multiple geomorphic processes. There are several agents (eg. tectonic forces, water, wind) that come into play in the formation of these features. However, geologists have named and grouped these into different geomorphic environments on the basis of the dominant surface processes and agents responsible for the formation of the landform. Fluvial geomorphic environment is most pertinent to this study, as it represents the land features formed and shaped by concentrated channel flow. Some of the geomorphic features like floodplain, flood-plain step, flood-plain playa, flood-tidal delta etc. belonging to the fluvial environment have a history of floods associated with them and represent flood-prone areas. According to the definition adopted by USDA (1999), floodplains are the nearly level plains along a stream that get flooded frequently during high flows, and are built of sediments deposited during these floods or due to lateral migration of streams. Flood-plain step, on the other hand, is a terrace like alluvial surface within a valley that is frequently inundated by the overflows from streams during floods. Thus, the map units which have their geomorphic description same as these flood features were selected. This description is contained in the *geomdesc* field of the *component* table in the SSURGO database.

Lacustrine environment (related to inland water bodies), Depressional grouping (low areas excluding permanent water bodies), Wetlands (related to vegetated or shallow wet areas, wet soils), and Water bodies (permanent water features) are some other landform groups that are potential indicators of flood prone areas. Water bodies were delineated through the earlier mentioned criteria *muname = water*. Other features are more relevant in certain specific regions. Lacustrine landforms like beach, delta plain, lake plain, for instance, would be pertinent near the Great Lakes. Depressional features are more extensive in glaciated areas of the Midwestern States, and have been observed to be frequently inundated.

### 4.2.5 Final selection criteria

The selection approach was implemented in ArcGIS by first joining the soil maps of study area with the *muaggatt* and *component* tables using mukey as the key link. The selection criteria was then executed by using the 'Select by attributes' feature, where following attribute query was made: [muname]='*water*' OR [geomdescr]='%*flood%'* OR [taxsuborder]='%*fluv%'* OR [floodfreqdcd] in (*'Rare','Occasional',Frequent',Very Frequent'*). The resulting selection corresponds to the flood-prone areas in the region.

However, note that it should not be considered as a final, exhaustive selection of flood-prone map units, as certain climatic, geomorphic or anthropogenic conditions in a region may warrant modification or customization in the selection criteria. For instance, cold climatic regions such as Alaska may require addition of certain kind of Gelisols or glacial landform features; certain physiographic regions such as glaciated areas in Midwestern States may demand inclusion of depression features; Aquolls would, perhaps, play an important role in certain swampy areas or wetlands; standard selection criteria may be rendered ineffective due to human activities such as new constructions in urban areas, dams, and tile drainage network in certain areas. Such observations, in fact, did come to the forefront during the studies carried out in the Northern Indiana counties. Moreover, there are several other attributes (such as type of vegetation, parent soil material = alluvium, etc.) that can also act as potential indicators of past flooding in an area.

### 4.3 Derivation of DEM based Flood Maps using OHRFC's stage data

Annual maximum stages for various major streams in Indiana were determined from the historical daily stage data (1950-1997) obtained from the Ohio River Forecast Centre (OHRFC). These annual peak stages were then fitted to Log Pearson III (LP3) distribution, and water surface elevation with return period of 100 years (Table 4.2) was determined at each of the OHRFC station. A raster with the above determined water surface elevation was generated, and DEM was subtracted from it to get the base flood inundation map at each of these stations. 10 m and 30 m resolution DEMs were used to get the two sets of such base flood inundation maps.

Table 4.2 : Estimated 1%-annual chance water surface elevations at OHRFC stations

| S No | OHRFC Station Identifier | Location (IN) | 1%-annual chance water surface elevation (m, above mean sea level) |
|---|---|---|---|
| 1 | ABTI3 | East Fork Whitewater River at Abington | 247.638 |
| 2 | BAKI3 | East Fork White River at Columbus | 189.139 |
| 3 | BEDI3 | East Fork White River at Rivervale | 155.066 |
| 4 | BFRI3 | E. Fork White River at Bedfort | 152.905 |
| 5 | CVGI3 | Wabash River at Covington | 153.389 |
| 6 | DCRI3 | St. Mary's River at Decatur | 239.236 |
| 7 | DEPI3 | Muscatatuck River at Deputy | 173.691 |
| 8 | HUFI3 | Wabash River at Terre Haute | 143.955 |
| 9 | LAFI3 | Wabash River at Lafayette | 161.824 |
| 10 | MTZI3 | Wabash River at Montezuma | 148.614 |
| 11 | RVTI3 | Wabash River at Riverton | 134.932 |
| 12 | SBVI3 | Big Blue River at Shelbyville | 231.533 |
| 13 | SERI3 | East Fork White River near Seymour | 173.767 |
| 14 | SHLI3 | East Fork White River at Shoals | 144.439 |
| 15 | VRNI3 | Vernon Fork of Muscatatuck R at Vernon | 187.140 |
| 16 | WLLI3 | East Fork White River at Williams | 150.028 |

### 4.4 Derivation of DEM based Flood Maps for lower order creeks

A significant majority of the detailed flood studies (eg. FEMA issued FIRMs or FIS) in the country, so far, has been along the major streams. The associated economic unviability and time constraints have kept the flood managers away from the smaller, lower order creeks. It is hypothesized that SFMs can provide an economically viable and quick-to-obtain option in these cases. To assess this hypothesis, flood inundation maps were developed along the lower order creeks using 30 m and 10 m resolution DEMs. First, the one-percent annual chance flow value was determined by applying LP3 distribution to the annual peak flow values obtained from the USGS gage station record on each of these streams. Next, the HEC-RAS model was developed for each stream using these DEMs.

Table 4.3 : Estimated 1%-annual chance flows for Lower Order Creeks in Indiana

| S No | Lower Order Streams | IN Region | USGS gage | 100-year return period discharge, cfs |
|---|---|---|---|---|
| 1 | Cobb Ditch near Kouts | Northern Lake Plains | 05517890 | 1366 |
| 2 | Fish Creek at Hamilton | | 04177720 | 1295 |
| 3 | Galnea River near Laporte | | 04096100 | 1125 |
| 4 | Iroquois River at Rosebud | | 05521000 | 652 |
| 5 | Juday Creek near South Bend | | 04101370 | 308 |
| 6 | Rimmell Branch near Albion | | 04100295 | 55 |
| 7 | Solomon Creek near Syracuse | | 04100377 | 450 |
| 8 | Spy Run Creek at Fort Wayne | | 04182810 | 1527 |
| 9 | Weesau Creek near Deedsville | | 03328430 | 640 |
| 10 | Big Lick Ceek near Hartford City | Central Till Plains | 03326070 | 2300 |
| 11 | Buck Creek near Muncie | | 03347500 | 2068 |
| 12 | Crooked Creek at Indianapolis | | 03351310 | 4942 |
| 13 | Kokomo Creek near Kokomo | | 03333600 | 1410 |
| 14 | Little Buck Creek near Indianapolis | | 03353637 | 3640 |
| 15 | Pleasant Run at Arlington | | 03353120 | 2674 |
| 16 | Plum Creek near Bainbridge | | 03357350 | 1202 |
| 17 | Westfork Whitelick Crk at Danville | | 03353700 | 9838 |
| 18 | Whitewater River near Economy | | 03274650 | 1398 |
| 19 | Back Creek at Leesville | Southern Hills and Lowlands | 03371520 | 16440 |
| 20 | Brush Creek near Nebraska | | 03368000 | 8390 |
| 21 | Busseron Creek near Hymera | | 03342100 | 2152 |
| 22 | Crooked Creek near Santa claus | | 03303400 | 5633 |
| 23 | Hall Creek near St. Anthony | | 03375800 | 10252 |
| 24 | Harberts Creek near Madison | | 03366200 | 2307 |
| 25 | Little Indian Creek near Galena | | 03302300 | 7386 |
| 26 | Patoka River near Hardinsburg | | 03374455 | 5988 |
| 27 | Stephens Creek near Bloomington | | 03372300 | 6556 |
| 28 | Westfork Blue River at Salem | | 03302680 | 7513 |

The 1-D hydraulic model was run for the 100-year return period peak flow value, and the computed water surface elevation(s) at different cross-sections were then exported to ArcGIS. In ArcGIS, HEC-GeoRAS program was used to interpolate these water surface elevations to generate a water-surface TIN, from which 10 m and 30 m DEMs were subtracted to obtain the flood inundation extents and depths.

## 4.5 Comparison of SFMs with other flood maps

The performance of SFMs was evaluated by comparing the inundation extents predicted by them against the observed extents, as well as against the extents predicted by the other flood inundation maps (viz. FIRMs and DFMs) commonly used by the floodplain managers. These validation studies were carried out along numerous streams in Indiana, and several other flood-hit places in Washington, Minnesota, and Wisconsin. The predicted or observed flood inundation extents of different FIMs were overlapped with each other in ArcGIS, and initially a visual comparative assessment of SFMs was made. Although such a qualitative assessment (visual comparison) has its own significance, it is equally imperative to quantify the comparison results for a more objective and scientific assessment of SFMs. F-statistic, an index as defined by Equation 1, is commonly used to quantify the goodness-of-overlap of two maps (Bates and De Roo, 2000; Horritt and Bates, 2002; Tayefi et al., 2007).

$$F = 100 * \frac{\mathrm{A_{ab}}}{(\mathrm{A_a} + \mathrm{A_b} - \mathrm{A_{ab}})} \qquad \text{Equation 1}$$

where $A_a$ and $A_b$ are the areas of flood extents observed or predicted by the flood maps A and B respectively, $A_{ab}$ is the common area of overlap between the two maps. As evident through the schematic in Figure 4.1, *F* simply represents the percentage of combined predicted area (a+b-ab) that is commonly (ab) predicted by both the maps. Higher the *F* value, better the overlap; *F* equal to 100 corresponding to a perfect overlap, and F equal to 0 meaning no overlap.

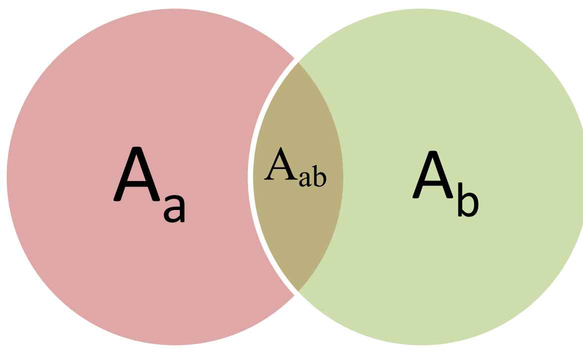


Figure 4.1 : Schematic of variables used in F-statistic definition

To calculate the F-statistics, study area boundaries for each of the validation study needed to be defined. These boundaries were digitized in ArcGIS such that the study area was sufficiently wide enough to incorporate all the flood map delineations along the stream reach of interest to the study, and did not include its tributaries. The tributaries were excluded for a fair comparison, as the hydraulic modeling in derivation of all the DEM based flood inundation maps (including FIRMs) were restricted to the main stream, and the SFM flood extents, on the other hand, extend even to the remote corners of a county. Next, the flood maps were clipped to the study area(s), and their intersection with the base flood map was taken. The polygon features post the clipping and intersection operation in ArcGIS constituted the individual flood map areas ($A_a$, $A_b$) and the overlap areas ($A_{ab}$) respectively. The goodness-of-overlap of SFMs and other flood risk maps with the reference flood maps was then quantified as F-statistics using Equation 1 . In the absence of any guidelines suggesting an acceptable value of F-statistic for the qualification of an overlap as good, the F-statistics of SFMs were compared to the F-statistics of FIRMs or DFMs in the region.

Specifically, such comparison analysis was first carried out for the study areas located along major streams in Indiana, with FIRMs as the base map, and the performance of SFM was evaluated against the performance of DEM based flood inundation map (DFM) derived using historical stage data obtained from OHRFC. As mentioned earlier, there are lot of uncertainties associated with the FIRM predictions themselves. Thus, next, the flood extents predicted by SFMs and FIRMs were compared against the actual inundation extents observed during the recent flood events in the study areas. Finally, the efficacy of SFMs was assessed along the lower order creeks in Indiana by comparing its performance with that of DEM derived flood maps (DFMs), with FIRM as the base map.

# CHAPTER 5. RESULTS AND DISCUSSION

The flood extents predicted by SSURGO based floodplain maps (SFMs) and their comparison with other flood risk maps have been presented and discussed in this section. The entire set of soil survey based floodplain maps derived for the study areas has been appended in the end for the reference purpose.

## 5.1 Validation results in Indiana with FIRMs as the reference base map

FIRMs were chosen as the reference for evaluating SFMs, as they form the regulatory standard, and FEMA and local flood managers consider them to be the most reliable option at hand for designating flood risk zones in a community. However, it must be reiterated here that even though the FIRMs have been chosen as reference base maps in this section, there are lot of uncertainties associated with the flood extents suggested by these maps. Jung and Merwade (2012) showed that the uncertainty bounds in the inundation area associated with these maps can range anywhere from 1.4% to 29% depending on the accuracy in topography, roughness, and flow data employed during their derivation. Thus, any deviation of the predicted flood extents from the FIRM extents should be interpreted accordingly.

F-statistics, a measure of the goodness-of-overlap as defined in the previous chapter, with FIRM as the reference map has been tabulated for SFMs near 15 OHRFC stations in Table 5.1. The median and mean F-statistic for SFMs are 71.4% and 70.1% respectively, with a standard deviation of 10.7%.

The natural question that follows these results is: Is 71% of overlap (a scenario closely resembled, for instance, by the floodmaps near ABTI3, as shown in Figure 5.1) with FIRMs good enough? There is no short, definitive answer to this question. There are no guidelines suggesting an acceptable lower limit of the F-statistic for a good overlap. So, instead of qualifying a SFM as acceptable or unacceptable merely based on this F-statistic, the relative evaluation of SFM and other DFMs with the common reference map (FIRMs in this case) was carried out. Based on this relative evaluation, the potential of SFM as an alternative approach was assessed.

Table 5.1 records the goodness of overlap of SFMs and DFMs with the corresponding FIRMs. The visual assessment of floodmaps' overlaps, as in Figure 5.1 and Figure 5.2, helps us qualitatively analyze their relative performance. As can be seen from these results, prediction capability of SFMs are at par with that of flood maps derived using 10 m DEM and actual stages. Mean and median overlaps with FIRMs in both cases are around 72%. Also, in general, SFMs tend to predict smaller flood extents as compared to FIRMs. The above results indicate that an average SFM flood extent area is expected to be 18-20% lower than the FEMA predictions. DFMs, on the other hand, are found to err on the both sides of the FIRM estimates, with a typical DFM prediction differing by 19 to 27 percentage points. Surprisingly, the use of coarser resolution (30 m) DEMs is found to have negligible influence on the flood extents predicted by DFMs along these major streams.

Table 5.1 : Overlap of SFMs with FIRMs near OHRFC stations

| | **FIRM** | **DFM: 30m (10m)** | | **SFM** | |
|---|---|---|---|---|---|
| OHRFC station | Area, $km^2$ | dfm/firm, % | *F* (dfm,fema) | sfm/firm, % | *F* (sfm,firm) |
| mtzi3 | 12.2 | 100.6 (100.6) | 99.7 (99.7) | 96.8 | 88.5 |
| hufi3 | 46.06 | 99.6 (100.3) | 87.9 (87.9) | 91.3 | 82.5 |
| sbvi3 | 10.27 | 156.2 (156.4) | 63.6 (63.6) | 82.6 | 77.4 |
| cvgi3 | 17.52 | 89.6 (89.4) | 88.6 (88.6) | 90.1 | 89.1 |
| abti3 | 1.5 | 138.7 (138.0) | 69.6 (69.5) | 103.2 | 75.8 |
| lafi3 | 6.3 | 17.7 (82.8) | 17.7 (73.1) | 75 | 74.5 |
| dcri3 | 19.71 | 85 (83.66) | 68.4 (68.3) | 72.2 | 68.3 |
| seri3 | 117.66 | 122.6 (121.1) | 72.9 (73.1) | 112.7 | 67.7 |
| rvti3 | 14.74 | 195.1 (191.9) | 49.0 (50.1) | 114.9 | 66.6 |
| baki3 | 74.32 | 113.2 (113.63) | 60.5 (60.5) | 88.1 | 65.2 |
| shli3 | 12.72 | 80.5 (80.4) | 78.1 (78.1) | 74.4 | 64.4 |
| wlli3 | 19.37 | 82.1 (82.6) | 81.9 (82.1) | 71.9 | 61.7 |
| depi3 | 1.05 | 121.9 (120) | 54.1 (55.0) | 118.5 | 56.6 |
| vrni3 | 1.17 | 77.1 (79.5) | 71.6 (73.0) | 46.1 | 44.1 |
| bfri3 | 7.18 | 88.0 (88.2) | 87.0 (87.1) | 77.7 | 74.6 |
| bedi3 | 10.18 | 97.3 (97.5) | 88.7 (88.8) | 87.4 | 78.1 |
| | | **Median *F*** | **72.2 (73.1)** | **Median *F*** | **71.4** |

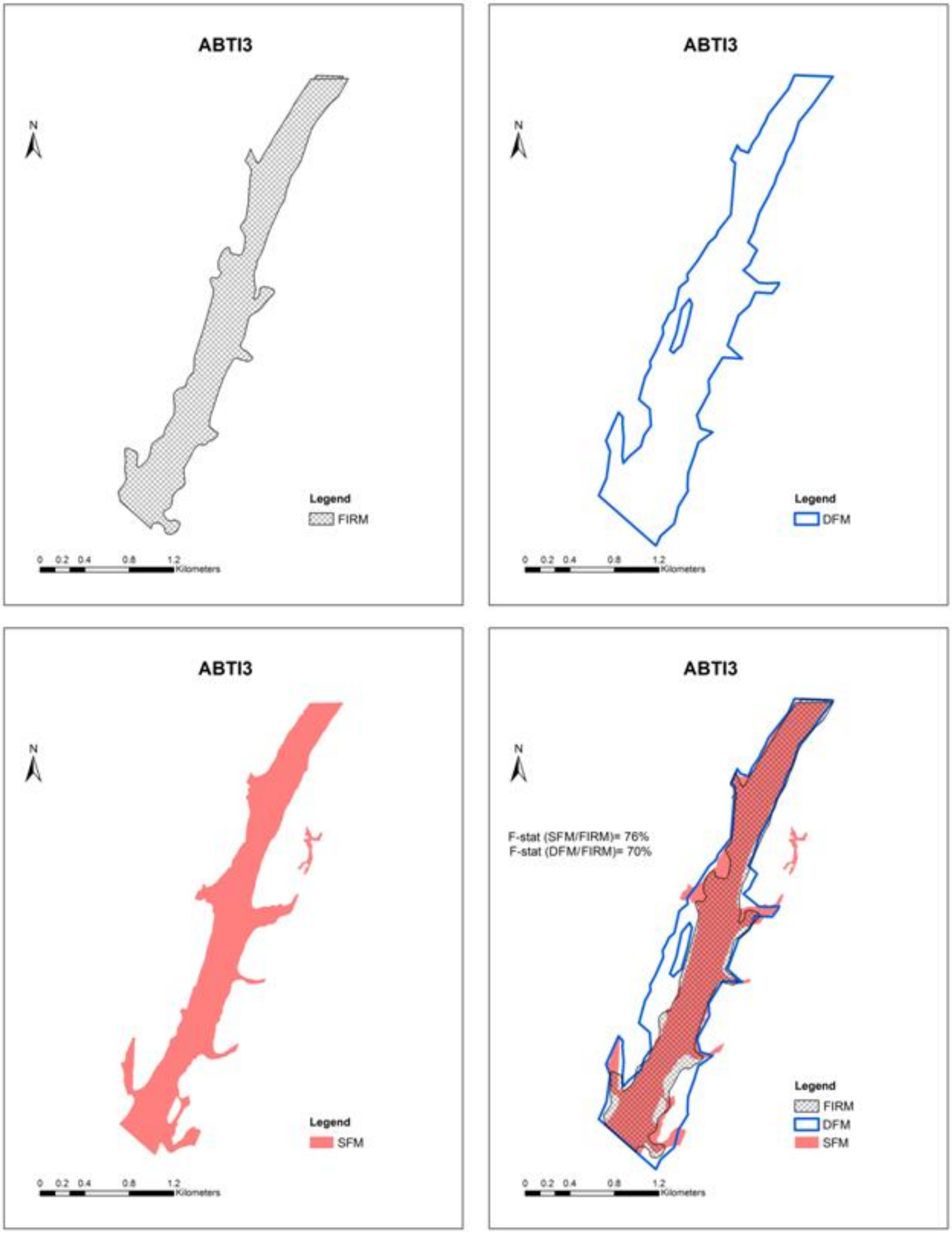


Figure 5.1 : Comparison of different floodmaps near ABTI3

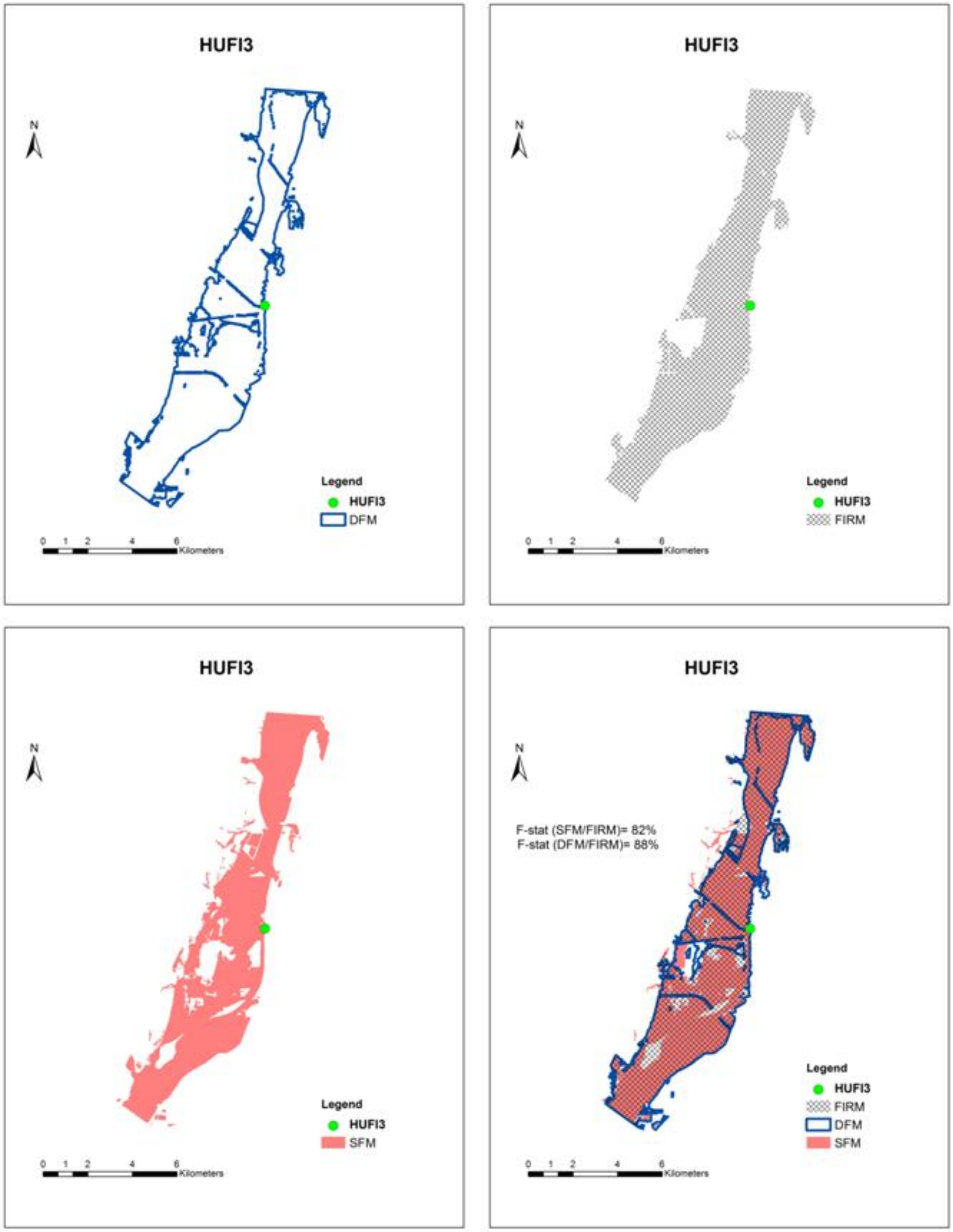


Figure 5.2 : Comparison of different floodmaps near HUFI3

There can be several reasons for the smaller flood extent predictions by SFMs. One possible explanation can be linked to the fact that the flood frequency class (*floodfreqdcd)* of a soil survey map unit is determined by its dominant soil component. Thus, even though if a part of SSURGO map unit gets inundated during *rare* (20-100 years return period) flood events, the whole map unit, depending on the flood frequency of its dominant soil component, might end up getting *very rare* (100-500 years) flood frequency class assigned to it. In fact, it has been noticed that, quite often the flood frequency class even changes abruptly from *occasional* (2-20 years) to *none* (>500 years) across a map unit boundary. A FIRM, on the other hand, attempts to identify all those areas that are likely to get inundated in case of a 100-year return period flood event . The loss of accuracy in flood frequency information across map unit boundaries, thus, may be responsible for smaller flood extents of SFMs.

Moreover, in a separate research, Cook and Merwade (2009) found that the flood extent predicted by the topography based flood risk maps reduce significantly (7%-33%) with the incorporation of river bathymetry details. In such a scenario, where the flood extents predicted by a FIRM is likely to reduce with the inclusion of a more accurate bathymetry, the agreement between SFMs and FIRMs is more than that reflected by the calculated median $F$ value ( = 71.4%).

### 5.2 Validation results with the observed flood extents as the reference

A flood risk map is meant to predict the areas likely to get inundated in the event of a flood of design magnitude (usually, 100-year flood). The ultimate performance evaluation of any flood map, thus, ought to be in terms of its ability to predict the actual flood extents observed during a real flood event of 100-year return period. For this reason, SFMs and FIRMs were evaluated against the observed flood extents.

The overlaps of SFMs and FIRMs with the observed flood extents have been tabulated in the Table 5.2-5.5. The flood extents of the FIRMs considered in this study correspond to the floods of 100-year return period. Thus, for a fair comparison, the observed flood extents used as reference base map should also ideally have a return period of 100 year. Realistically, however, it is very tough to identify the actual 100-year return period flood events, along with their flood extents, from the available flood records. The field investigation reports of the floods observed in the study areas specify the range of return period of these floods viz.: >100 years, 50-100 years, 25-50 years, 10-25 years. For a meaningful comparison, the two classes of floods bordering on the 100-year flood frequency (i.e. >100 years and 50-100 years) have been considered for the analysis. Further, since *very rare* (100-500 years return period) floods were excluded during the derivation of SFMs, comparison of SFM extents should be made with the observed flood extents from 50-100 years flood frequency class only. However, very few floods observed in the study area(s) fall in that flood frequency range. Thus, the efficacy of SFMs is assessed for very rare flood events as well. The use of range of flood frequencies, instead of a single flood frequency for a comparative analysis means that a 100% overlap may not necessarily represent a perfect prediction of flood extents. Thus, the *F*-statistics and other results should accordingly be interpreted with caution.

Table 5.2 : Validation with observed flood extents in Indiana

| **Observed** | | | **FIRM** | | **SFM** | |
|---|---|---|---|---|---|---|
| **Jun 08 flood locations in Central & Southern IN** | Return period of flood, *yrs* | Area $km^2$ | firm/obs % | *F* (firm,obs) | sfm/obs % | *F* (sfm,obs) |
| Clifty Creek at Columbus* | >100 | 2.09 | 140.1 | 65.3 | 70.2 | 58.6 |
| White River at Newberry* | >100 | 1.08 | 101.1 | 92.6 | 102.4 | 92.8 |
| Youngs Creek at Franklin* | >100 | 2.63 | 92.2 | 91.1 | 78.2 | 72.3 |
| Haw creek at Columbus* | >100 | 2.91 | 72.4 | 62.1 | 40.3 | 35.8 |
| Hurricane Ck at Columbus* | 50-100 | 1.38 | 114.9 | 80.3 | 67.8 | 56.8 |
| E. Fork White at Seymor* | 50-100 | 21.80 | 110.2 | 86.8 | 92.3 | 82.7 |
| White R. at Worthington* | 50-100 | 0.58 | 99.0 | 82.3 | 106.8 | 88.0 |
| E Fork White at Columbus | 25-50 | 0.63 | 113.4 | 84.4 | 82.8 | 67.8 |
| White River at Spencer | 25-50 | 1.86 | 106.5 | 89.7 | 95.6 | 84.7 |
| Blue River at Edinburgh | NA | 0.65 | 190.9 | 52.4 | 105.2 | 71.4 |
| White R. at Martinsville | NA | 1.63 | 123.1 | 81.1 | 121.1 | 36.5 |
| Eel River at Worthington | NA | 0.27 | 46.4 | 35.6 | 72.3 | 39.8 |
| Only * flood events have been considered for the computation of median *F* | | | **Median *F*** | 82.3* | | 72.3* |

The comparison study in Indiana (Table 5.2) indicates that a SFM is typically successful in predicting around 72.3% of the observed flood extents. Although FIRMs make slightly better predictions here, there is only a 10 percentage point difference in the performance of two . Similar observations are made in other states as well. In western Washington, SFMs (median *F*= 79.3%) and FIRMs (median *F*= 90.3%) are able to predict most of the areas that were inundated during January 2009 floods (Table 5.3). The predicted flood extents consistently provide a fitting overlap (median *F* = 71.5% and 91.8 % respectively for SFMs and FIRMs) with the observed flood extents in southern Wisconsin as well (Table 5.4). All states considered together, SFMs predict observed flood extents with median *F*-statistics of 72% as against *F*=87% for FIRMs. The median *F*-statistics change to 78% for SFMs and remains unchanged for FIRMs when only the floods belonging to 50-100 years return period are considered.

Table 5.3 : Validation with observed flood extents in Washington

| Observed | | | FIRM | | SFM | |
|---|---|---|---|---|---|---|
| **Jan 2009 flood locations in Western WA** | Return period of flood, *yrs* | Area *km²* | firm/obs *%* | *F* (firm,obs) | sfm/obs *%* | *F* (sfm,obs) |
| Stillaguamish River near Arlington* | >100 | 17.57 | 91.1 | 90.3 | 93.3 | 83.5 |
| S Prairie Creek at South Prairie* | >100 | 0.64 | 83.3 | 71.9 | 115.4 | 79.3 |
| Totl River near Carnation* | 100 | 10.00 | 102.6 | 91.8 | 96.0 | 70.0 |
| Cedar River near Renton | 50 | 0.21 | 154.5 | 62.0 | 449.0 | 19.4 |
| Newaukum River near Chehalis | 50 | 10.11 | 130.0 | 53.6 | 123.5 | 76.0 |
| Puyallup River near Orting | 25-50 | 2.50 | 240.7 | 37.2 | 190.7 | 47.2 |
| Snoq. R near Snoqualmie | 10-25 | 5.82 | 127.2 | 63.1 | 102.4 | 96.4 |
| Only * flood events have been considered for the computation of median *F* | | | **Median *F*** | 90.3* | | 79.3* |

Table 5.4 : Validation with observed flood extents in Wisconsin

| Observed | | | FIRM | | SFM | |
|---|---|---|---|---|---|---|
| **Jun 2008 flood locations in Southern WI** | Return period of flood, *yrs* | Area, *km²* | firm/obs *%* | *F* (firm,obs) | sfm/obs *%* | *F* (sfm,obs) |
| Kickapoo R at Gaysmills* | >100 | 3.33 | 102.0 | 92.3 | 98.6 | 84.3 |
| Kickapoo R at La Farge* | >100 | 1.57 | 111.8 | 78.9 | 120.4 | 77.3 |
| Baraboo R at Reedsburg* | >100 | 2.14 | 98.1 | 93.0 | 91.9 | 74.6 |
| Baraboo at Rock Springs* | >100 | 0.54 | 95.6 | 94.0 | 82.0 | 71.5 |
| Crawfish R at Milford* | >100 | 0.39 | 94.2 | 92.3 | 106.0 | 66.0 |
| Rock River at Janesville* | >100 | 2.51 | 122.8 | 78.1 | 91.6 | 63.0 |
| Rock River at Jefferson* | >100 | 1.80 | 88.8 | 86.9 | 91.3 | 56.7 |
| Rock River at Beloit* | >100 | 1.80 | 130.9 | 76.0 | 169.2 | 56.3 |
| Rock R at Fort Atkinson* | 50-100 | 83.14 | 100.6 | 91.8 | 110.8 | 77.7 |
| | | | **Median *F*** | 91.8 * | | 71.5* |

Table 5.5 : Validation with observed flood extents in Minnesota

| Observed | | | FIRM | | SFM | |
|---|---|---|---|---|---|---|
| **Sep 2010 flood locations in MN** | Return period of flood, *yrs* | Area, $km^2$ | firm/obs, % | *F* (firm,obs) | sfm/obs, % | *F* (sfm,obs) |
| Straight River at Faribault* | >100 | 0.69 | 118.3 | 82.5 | 39.4 | 39.3 |
| Maple Creek at Owatonna | 50-100 | 1.81 | 102.6 | 89.0 | 106.3 | 71.1 |
| Middle Fork near Pine Island* | >100 | 1.10 | 109.9 | 85.6 | 83.9 | 73.5 |

Additionally, as noted earlier in validation study along major streams (Section 5.1), SFMs tend to predict smaller flood extents than the FIRMs. However, no such distinct trend is recognized when the comparison is made with the observed flood extents. Although the SFM flood extents are smaller than the observed flood extents in majority of the cases (Figure 5.3), it does not conclusively suggest under-prediction. First of all, most of the observed floods have flood frequency greater than 100 years, whereas SFM flood extents are, in general, found to align most closely with the 100-year flood extents. In these cases, theoretically, a SFM is expected to have flood extents smaller than the observed flood extents. For the remaining flood classes, as expected by a similar line of argument, flood extents predicted by SFMs are, in general, larger than the observed flood extents. Nevertheless, SFMs do exhibit unexpected behavior in certain locations as discussed in the following paragraphs.

Further, SFMs are found to predict the observed flood extents with consistently higher accuracy (median $F$ = 78%) in the less developed areas (developed land use < 20%). The performance tends to dip as the percentage of developed area increases in the study region (Table 5.6, Figure 5.4). This effect of urban land use on the prediction capability

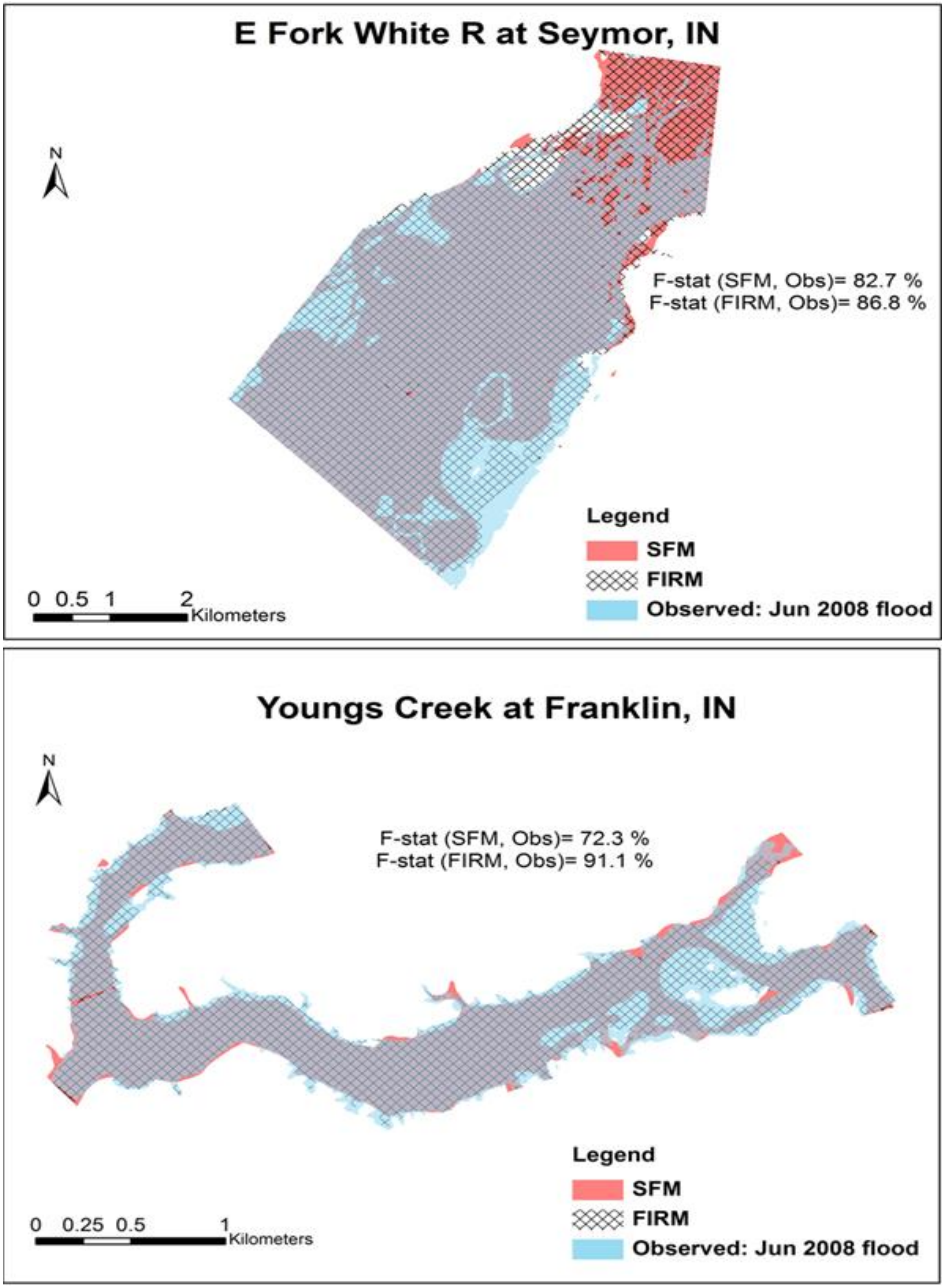


Figure 5.3 : Observed flood extents and apparent under-prediction by SFMs

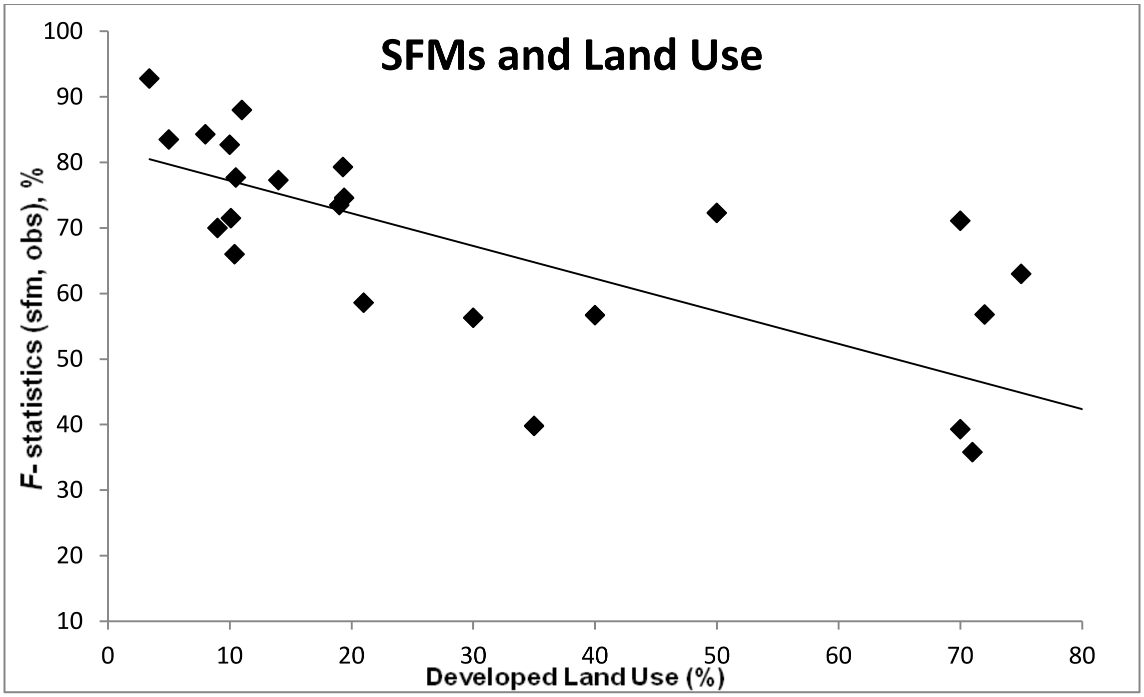


Figure 5.4 : Effect of developed land use on the performance of SFMs

of a SFM is not just limited to its overall flood extents, the local effects are also evident in certain cases. Consider, for instance, Cedar Creek near Renton, WA, and Rock River at Beloit, WI (Figure 5.5). In both the cases, the flood extents of SFMs abruptly changes as the stream enters the regions of high urban land development. The procedure(s) adopted by the soil survey staff for the estimation of flood frequency class of a map unit offers some plausible explanation for this phenomenon. Hydrologic and hydraulic engineering studies, if available, are given first preference in the determination of flood-prone areas in a region (NRCS, n.d.). Thus, any effects of existing dams, levees, or any other structures on the predicted inundation extents are duly accounted for in this process. However, the land use keeps changing in an urban area, usually at a pace much faster than the soil

Table 5.6 : Land use and overlap of SFMs with observed flood extents

| | Streams | State | Developed Land Use (%) | F (sfm, obs), % |
|---|---|---|---|---|
| Low Density Developed Areas | White River at Newberry* | IN | 3.4 | 92.8 |
| | Stillaguamish River near Arlington* | WA | 5.1 | 83.5 |
| | Kickapoo River at Gaysmills* | WI | 8.0 | 84.3 |
| | Totl River near Carnation* | WA | 9.1 | 70.0 |
| | E. Fork White at Seymor* | IN | 10.0 | 82.7 |
| | Baraboo River at Rock Springs* | WI | 10.1 | 71.5 |
| | Crawfish River at Milford* | WI | 10.4 | 66.0 |
| | Rock River at Fort Atkinson* | WI | 10.5 | 77.7 |
| | White River. at Worthington* | IN | 11.0 | 88.0 |
| | Kickapoo R at La Farge* | WI | 14.1 | 77.3 |
| | Middle Fork near Pine Island | MN | 19.0 | 73.5 |
| | S Prairie Creek at South Prairie* | WA | 19.3 | 79.3 |
| | Baraboo River at Reedsburg* | WI | 19.4 | 74.6 |
| High Density Urban Areas | | | | |
| | Clifty Creek at Columbus* | IN | 21.2 | 58.6 |
| | Rock River at Beloit* | WI | 30.3 | 56.3 |
| | Eel River at Worthington | IN | 35.1 | 39.8 |
| | Rock River at Jefferson* | WI | 40.5 | 56.7 |
| | Youngs Creek at Franklin* | IN | 50.4 | 72.3 |
| | Straight River at Faribault* | MN | 70.1 | 39.3 |
| | Maple Creek at Owatonna | MN | 70.4 | 71.1 |
| | Haw creek at Columbus* | IN | 71.0 | 35.8 |
| | Hurricane Ck at Columbus* | IN | 72.3 | 56.8 |
| | Rock River at Janesville* | WI | 75.0 | 63.0 |

survey updates. The effects of any structure recently constructed across a stream (or even in the floodplain) would, thus, be not reflected in the SFM extents. More importantly, such detailed engineering studies are not available for all the communities. In such cases, surveyors turn to other evidence-based methods like correlating type of vegetation, soil or geomorphic features of an area to its flooding frequency. But this approach is not relevant in the case of urban areas because of the heavy anthropogenic influences. Typically, a

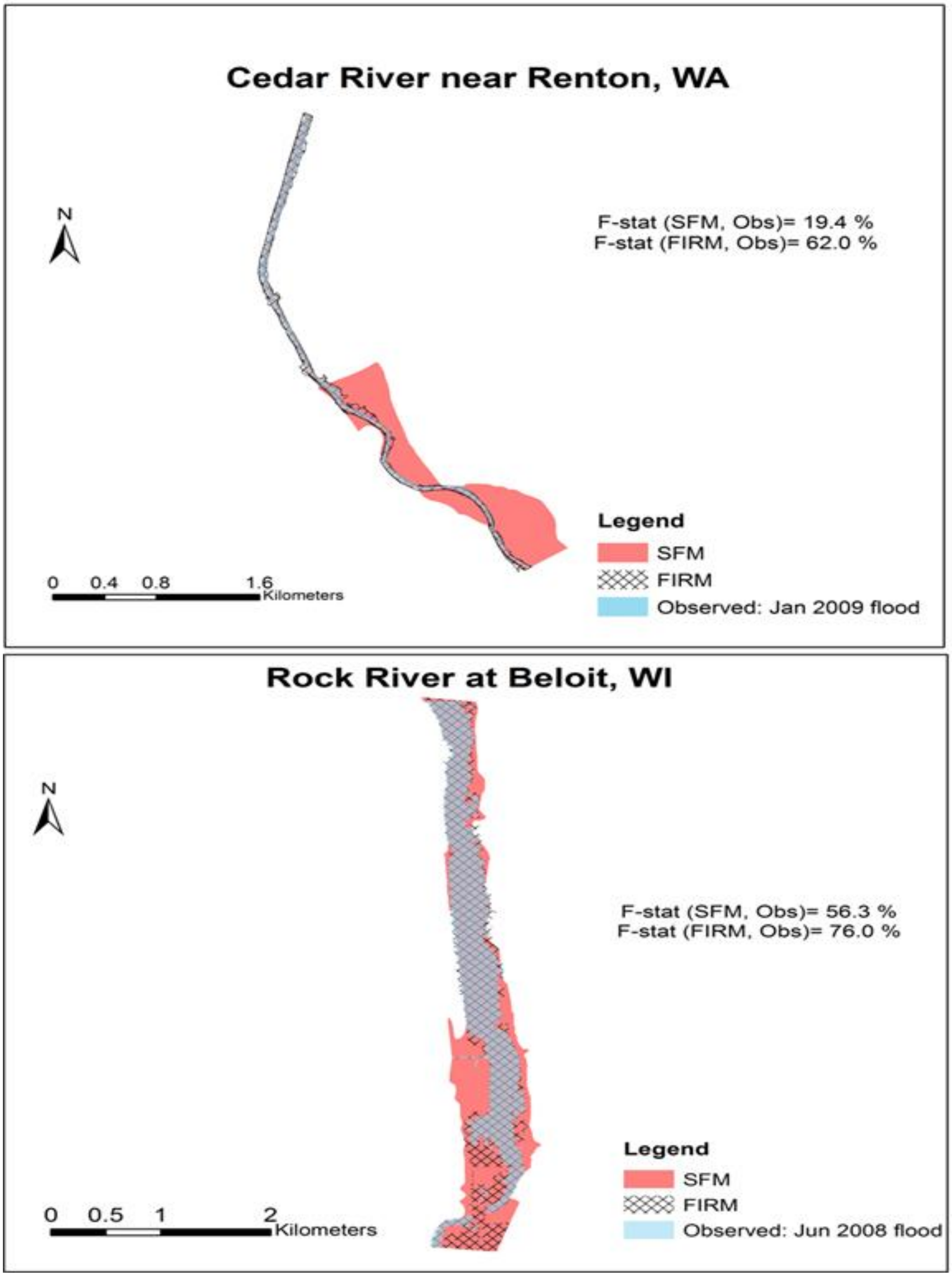


Figure 5.5 : Abrupt change in SFM flood extents near urban areas

large part of the urban land cover is impervious, and its original geomorphology is altered by the land use development activities such as cuts & fills. For the same reason, the other two selection criteria involved in the derivation of a SFM, viz. soil taxonomy and geomorphic description, are also rendered irrelevant in the urban areas. Other method adopted by the soil scientists involves collection of past flooding information from various reports, records, recollection by local people etc., and the computation of flooding frequency of the area is based on this past information. Again, any significant land use change in an urban area would mean that the computed flood frequency does not adequately represent its current state of flood-proneness. Consider, for example, Cedar River near Renton, WA (Figure 5.5); SFM indicates occasional flooding over its right

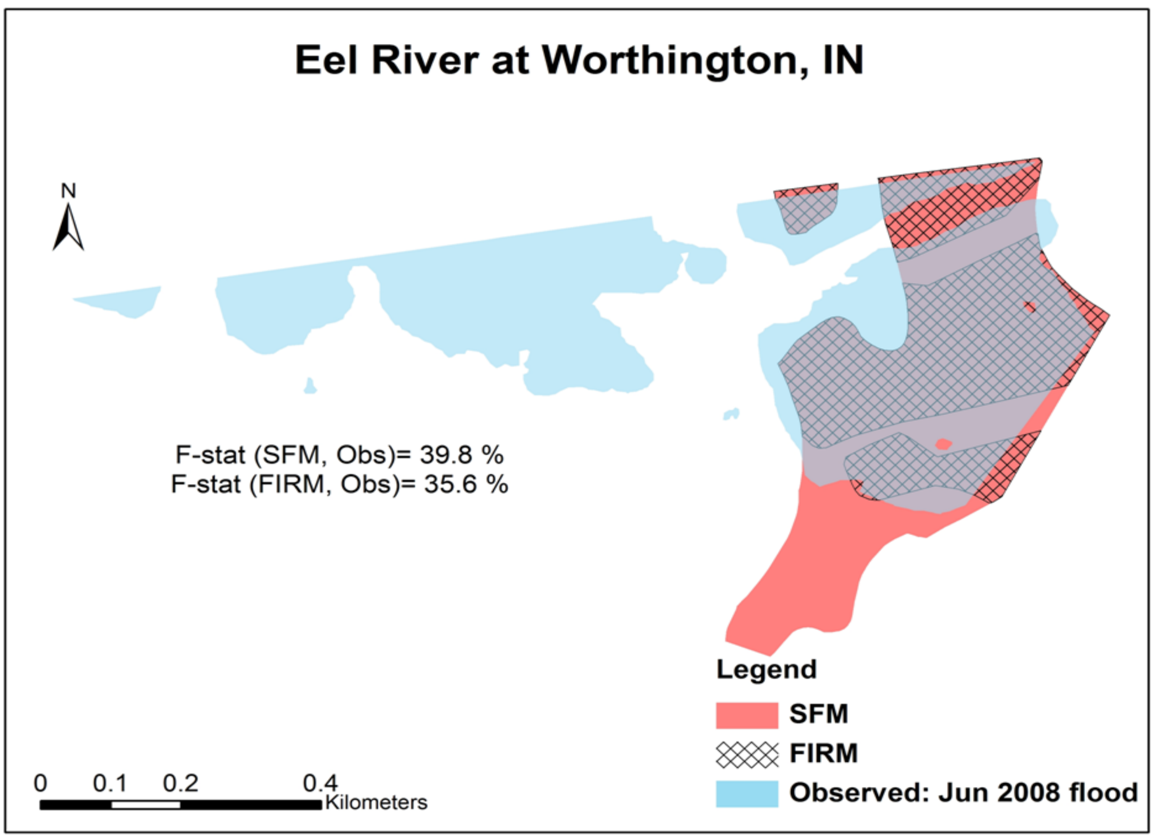


Figure 5.6 : Consistent SFM and FIRM predictions, and heavy flooding in Worthington

bank in the upstream reach, perhaps based on its past flooding information, whereas an adequate protection (levees) has been provided against the 100-year return period flood. Eel River at Worthington (Figure 5.6), on the other hand, represents a case where the SFM and FIRM predictions were consistent with each other, but there was a levee breach because of the high magnitude flood, and the urban areas overlooking west bank of the river were inundated beyond the predicted extents.

## 5.3 Validation of SFMs along Lower Order Creeks

A broader view of SFM of a region (Figure 5.7) reveals that SFMs, in comparison to FIRMs or DFMs, are much more dendritic in shape, reaching out to the areas even away from the major streams. This means that a SFM predicts flood extents even for the remote areas in a region. A FIRM is derived along a stream reach with heavy investments of time and money. As a result, most of the FIRMs have been developed only along major stream reaches or near major towns. SFMs, on the other hand, can be derived free-of-cost for an entire region within a time span of few minutes. Thus, the SFM approach potentially offers an economical alternative for the regions located along lower order creeks and for less developed regions where detailed flood studies have yet not been carried out. The results from the comparison of various flood risk maps near OHRFC stations establish the efficacy of SFMs along major rivers in Indiana. Also, it was discussed that the flood extents predicted by SFMs provide modest overlaps (comparable to FIRMs) with the observed flood extents along several streams in four different states. Next, the performance of these maps along lower order creeks is evaluated in this section.

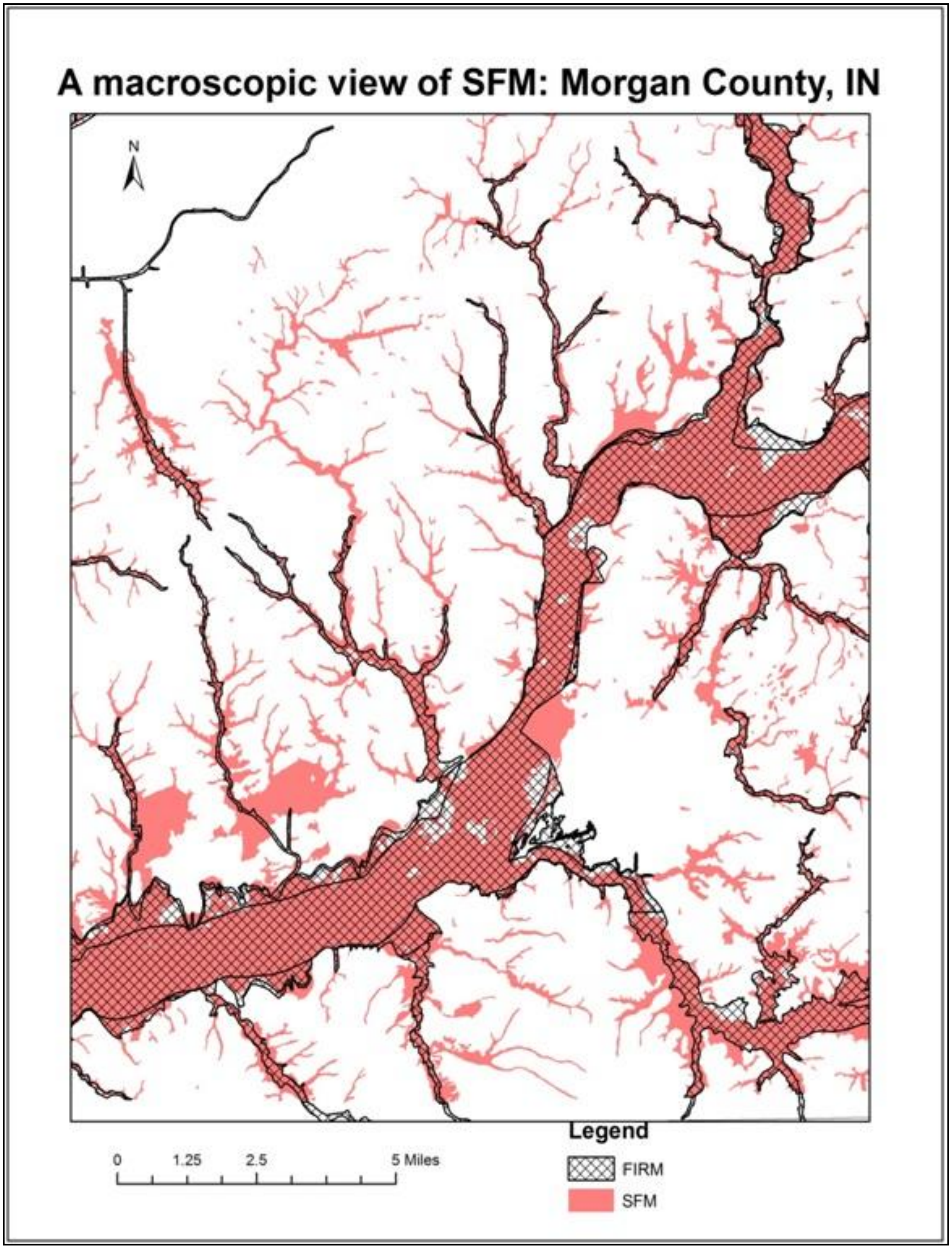


Figure 5.7 : Farther reaching (more dendritic) flood extents of SFMs in remote areas

SFMs were developed along 26 lower order creeks located all over Indiana. However, FIRMs and historical stage data were not available for most of these streams. Thus, the evaluation study was curtailed down to 15 creeks (Table 5.7) where FIRMs were available, and the flood maps were developed using hydraulic modeling (HEC-RAS and HEC-GeoRAS). The tabulated results indicate that SFMs (median *F* = 58.8) provide a

Table 5.7 : Validation along Lower Order Creeks in Indiana

| | | FIRM | DFM: 30m (10m) | | SFM | |
|---|---|---|---|---|---|---|
| | **Lower Order Creeks** | Area, $km^2$ | DFM/FIRM, % | F (dfm,firm) | SFM/FIRM % | F (sfm,firm) |
| Northern IN | Galena River | 0.17 | 179.3 (76.5) | 51.1 (63.6) | 194.8 | 43.0 |
| | Rimmel Branch | 0.93 | 68.9 (118.3) | 50.9 (44.6) | 84.4 | 55.9 |
| | Solomon Creek | 2.89 | 107.3 (199.0) | 32.3 (19.9) | 177.4 | 48.4 |
| | Spy Run Creek | 0.55 | 73.4 (72.7) | 49.6 (54.3) | 61.9 | 40.7 |
| | | | | | | |
| Central IN | Big Lick Creek | 0.89 | 107.4 (30.3) | 59.7 (19.6) | 135.0 | 74.1 |
| | Buck Creek | 3.48 | 59.0 (36.8) | 42.3 (21.2) | 52.0 | 35.7 |
| | Kokomo Creek | 0.64 | 66.5 (67.2) | 55.9 (56.1) | 95.7 | 65.2 |
| | Little Buck Creek | 1.61 | 108.8 (60.9) | 62.1 (52.2) | 167.6 | 63.5 |
| | W.Fork White Lick Creek | 1.83 | 88.9 (74.9) | 79.8 (64.7) | 103.1 | 73.6 |
| | Whitewater River | 0.75 | 159.0 (240.0) | 37.7 (29.4) | 95.8 | 39.2 |
| | | | | | | |
| Southern IN | Brush Creek | 0.87 | 309.0 (117.2) | 31.4 (65.2) | 140.7 | 60.1 |
| | Busseron Creek | 1.72 | 70.8 (129.1) | 42.9 (56.9) | 124.2 | 57.3 |
| | Crooked Creek | 1.71 | 70.2 (32.7) | 57.0 (15.8) | 123.1 | 76.8 |
| | Hall Creek | 3.00 | 74.7 (77.0) | 65.2 (67.3) | 113.0 | 70.4 |
| | Little Indian Creek | 2.21 | 94.5 (86.0) | 58.4 (64.8) | 123.8 | 58.8 |
| | | | **Median *F*** | 51.1 (54.3) | **Median *F*** | 58.8 |

marginally better overlap with FIRMs, as compared to DFMs derived from 10 m (median *F* = 54.3) and 30 m resolution (median *F* = 51.1) DEMs. However, *F*-statistics do not reflect the true performance of these maps, as a close look at the overlaps (Figure 5.8)

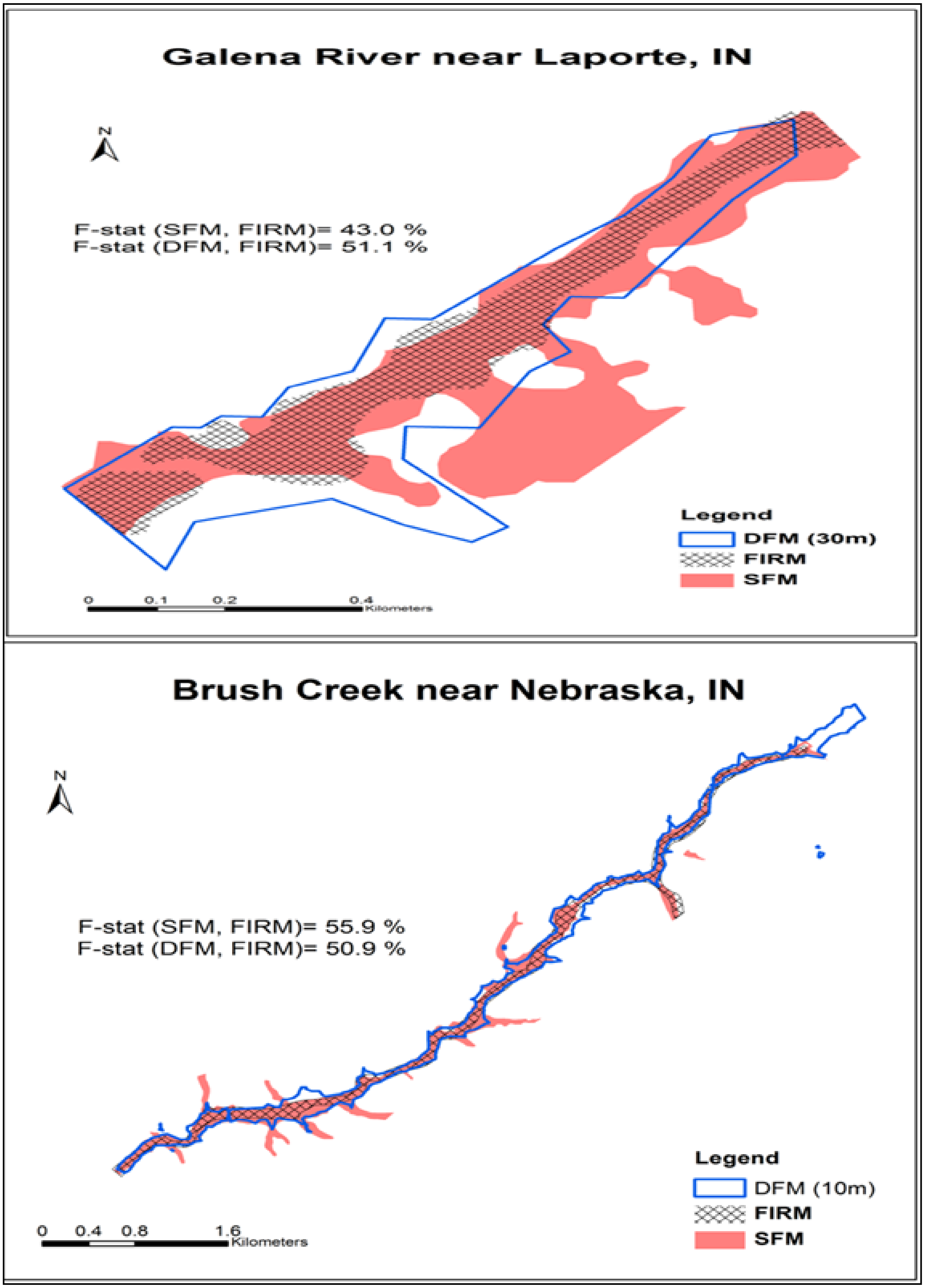


Figure 5.8 : Conservative flood extent prediction by SFMs along lower order creeks

reveal that most of them are successful in predicting the flood extents suggested by the FIRMs. The flood extents predicted by SFMs are observed to be, in general, larger than the FIRM extents, and this results in the lowering of *F*-values. Considering the uncertainties associated with the FIRM extents, it is desirable to have a slightly more conservative flood extent prediction by these maps.

There can be several reasons for the larger flood extent prediction by SFMs. One plausible reason can be the limitations imposed by the relatively large size of map units on the accuracy of flood extent prediction. The width of a map unit along a stream is typically observed to be larger than 45 m (USDA SCS, 1990). For relatively smaller floodplains found along lower order creeks, the accuracy limitation of this magnitude can lead to over-estimation or under-estimation of flood extents. Further, in the absence of detailed flood studies, the flood frequency class of map units in these regions is usually determined by the less accurate evidence-based methods discussed earlier. Another set of errors that becomes relevant in the case of lower order creeks, because of the scale issues, are the errors associated with the delineation of map units. These inaccuracies largely originate during the stereoscopic interpretation of aerial images, and the digitization of soil survey maps. The lateral shift observed in the floodplain extents of SFMs and FIRMs in certain cases (eg: Spy Run Creek (Figure 5.9), Little Buck Creek) is indicative of the potential translation errors originating during the process of map units delineation.

Scale issues are equally relevant in the case of DFMs. Flood maps derived from 30 m resolution DEMs are not expected to be very accurate, as the pixel size (30 m) is comparable to the floodplain extents along the lower order creeks. For this reason, 10 m DEMs were also considered. However, in both the cases, the overlap with the FIRMs was around 52% only. The prime reason for the differences in the extents predicted by DFMs and FIRMs is, perhaps, the difference in the accuracy of the river bathymetry used during their derivation. DEMs usually do not capture the surface representation of river bathymetry very accurately (Cook and Merwade, 2009). Thus, FIRMs are typically derived by incorporating the river bottom details obtained from ground surveys. DFMs used in this study, on the other hand, were derived using river bathymetry obtained from DEMs. The resulting errors in terrain elevations and water surface elevations are critical for the prediction accuracy of inundation extents along lower order creeks. Further, a lot of discontinuity in flood extents is observed in some of the DFMs (Figure 5.9). This discontinuity is largely due to the approximation errors originating during the interpolation of water surface elevations between the hydraulic model cross-sections. Although not reflected through median $F$ values, the significant differences in the flood extents of 10 m and 30 m DFMs (unlike the DFMs along OHRFC stations) underlines the importance of finer resolution terrain data along lower order creeks.

Furthermore, a distinct geographical pattern is also recognized in the SFM results. As evidently suggested by Table 5.7, SFM results are largely in agreement with FIRMs in the Central and Southern Indiana (Median $F$ =65%), where as in the Northern Lake Plains (Median $F$=47%) there is lesser agreement between the two. A detailed discussion on the performance of SFMs in the Northern Lake Plains region has been separately carried out in the next section.

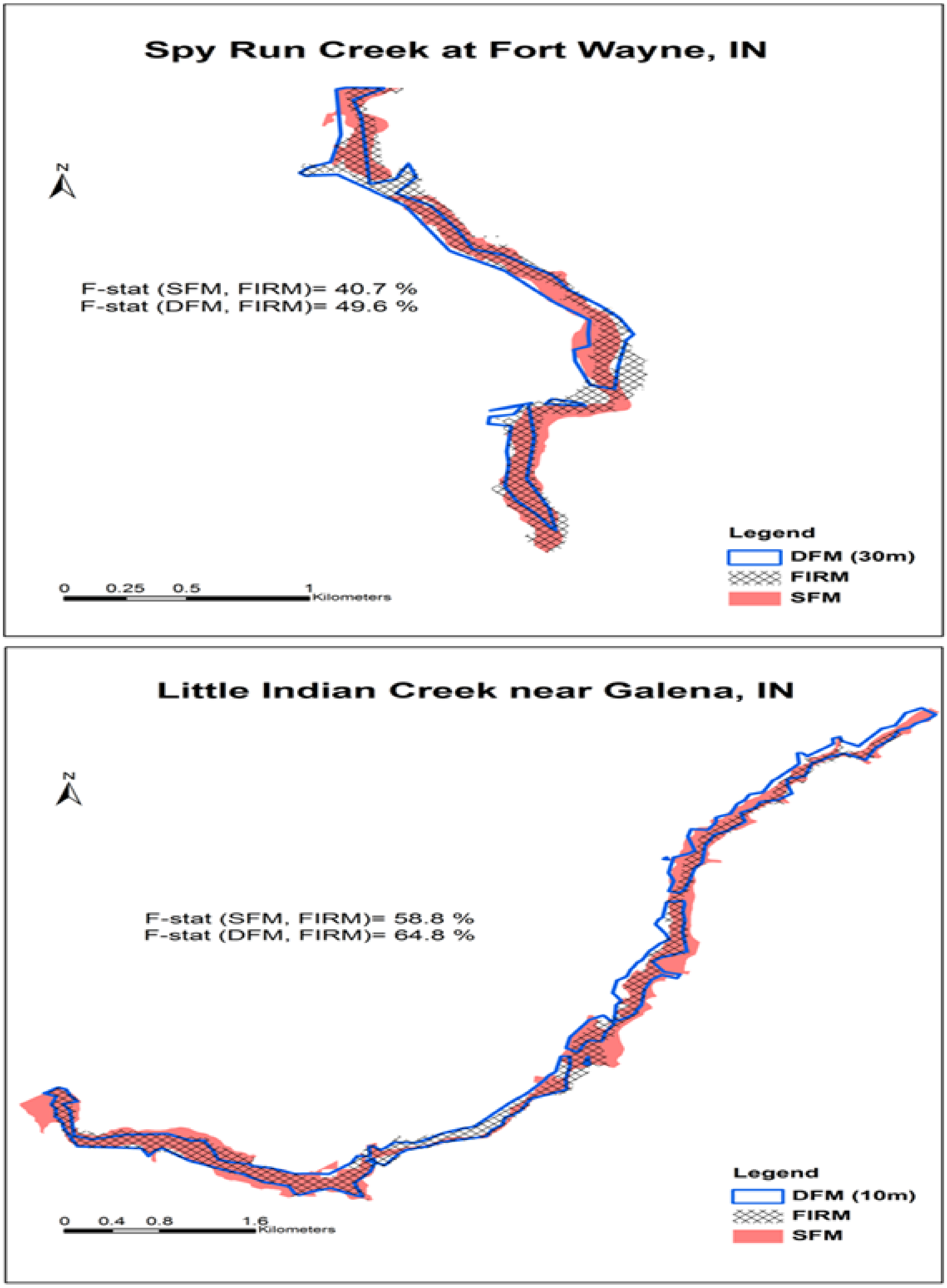


Figure 5.9 : Discontinuity in the flood extents predicted by DFMs

## 5.4 SFMs in Northern Indiana

SFMs provide lower percentage(s) of overlap with the reference flood maps in the Northern Lake Plains region, as compared to the Central and Southern regions of Indiana. The validation results (Table 5.7, 5.8, 5.9) for SFMs in Northern Lake Plains region of Indiana suggest that the standard criteria for selecting flood-prone map units is less effective in this region. A county-wise visual analysis of the SFMs in Indiana, with FIRMs as the primary reference map(s), further confirms the below-par performance (<55% overlap) of SFMs in Northern Indiana (Figure 5.10).

Table 5.8 : SFM performance near OHRFC stations in Northern Indiana region

| | FIRM | SFM | |
|---|---|---|---|
| **OHRFC stations in Northern IN** | Area, $km^2$ | sfm/firm, % | *F* (sfm,firm) |
| ORAI3: Ora on Tippecanoe River | 6.61 | 63.4 | 61.2 |
| ROOI3: Root Ski Haus on St Joseph R | 10.54 | 75.6 | 63.0 |
| FTWI3: Fort Wayne on Maumee R | 14.37 | 56.7 | 49.8 |

Table 5.9 : Comparison of SFMs with the observed flood extents in Northern Indiana

| | Observed | FIRM | | SFM: standard (customized) | |
|---|---|---|---|---|---|
| **Sep 08 floods in NW IN** | Area, $km^2$ | FIRM/Obs, % | *F* (firm,obs) | sfm/obs, % | *F* (sfm,obs) |
| Little Cal | 17.71 | 144.7 | 56.0 | 26.5 (151.8) | 19.7 (47.4) |
| Deep R | 2.57 | 98.8 | 87.5 | 51.5(112.7) | 41.6 (69.6) |
| Turkey Cr | 2.58 | 86.9 | 73.8 | 1.0(127.8) | 1.0 (51.7) |

The complex geological history of the Northern Lake Plains region offers a plausible explanation for this observed trend. The glacial advance and retreat experienced by the

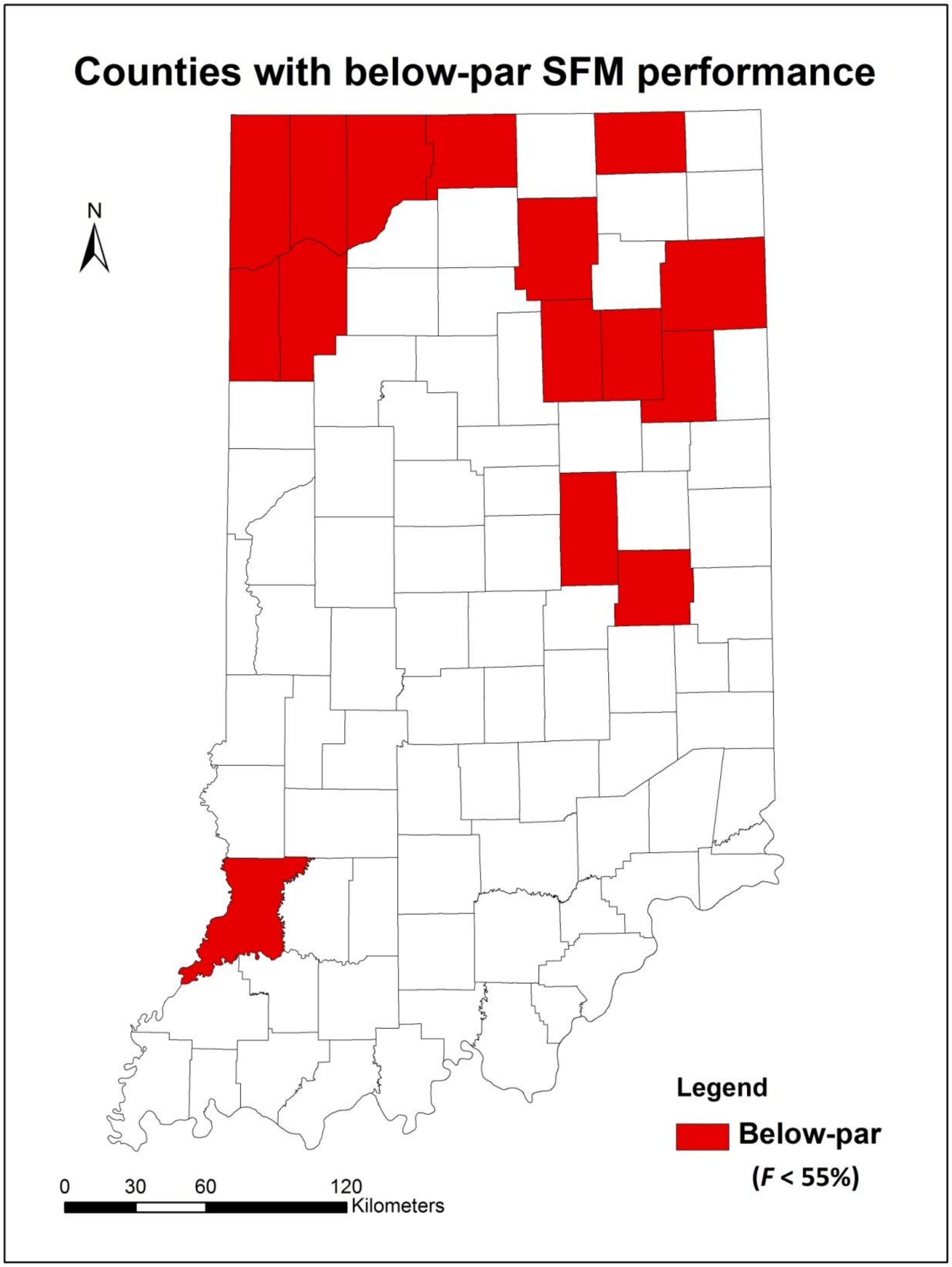


Figure 5.10 : Below-par performance of SFMs in northern Indiana counties

region in Pleistocene epoch resulted in the deposition of different types of sediments and landforms such as moraines, tills, outwash plains etc (Indiana Geological Survey, n.d.). Thus, the geomorphic description of soil map units in this region frequently contains terms like outwash plains, till plains, lake plains, instead of floodplains. Further, this region also has a dense network of trenched ditches and tile drainage, that has altered the natural hydrology of the area, especially in the Kankakee River basin. Until the end of the 19th century, the Kankakee River followed a meandering course through wetlands known as the Grand Kankakee Marsh. During the late 19th century and early 20th century, a network of ditches was constructed to drain the swamps, the river was dredged and channelized; consequently transforming the river course and its hydrology (Lake County Parks, n.d.). The region is also home to one of the largest urban and industrial conglomerates in the Midwestern United States. In particular, northern half of Lake, Porter and La Porte counties are effectively the suburbs of Chicago. As discussed earlier, the performance of SFMs tend to decrease with the increase in the developed land use in an area. These are some of the possible reasons for the drop in the performance of SFMs in the Northern Indiana region.

A new set of SFMs was developed for Northern Indiana counties with an additional criterion viz. *geomorphic description= 'depressions on lake plains, outwash plains'*. These SFMs showed marked improvement over earlier SFMs in terms of their conformation with the reference flood maps (Table 5.9; Figure 5.11). It can be conjectured from these improvements that certain regions may require customization of SFM selection criteria in accordance with their unique physiographic set up. Further,

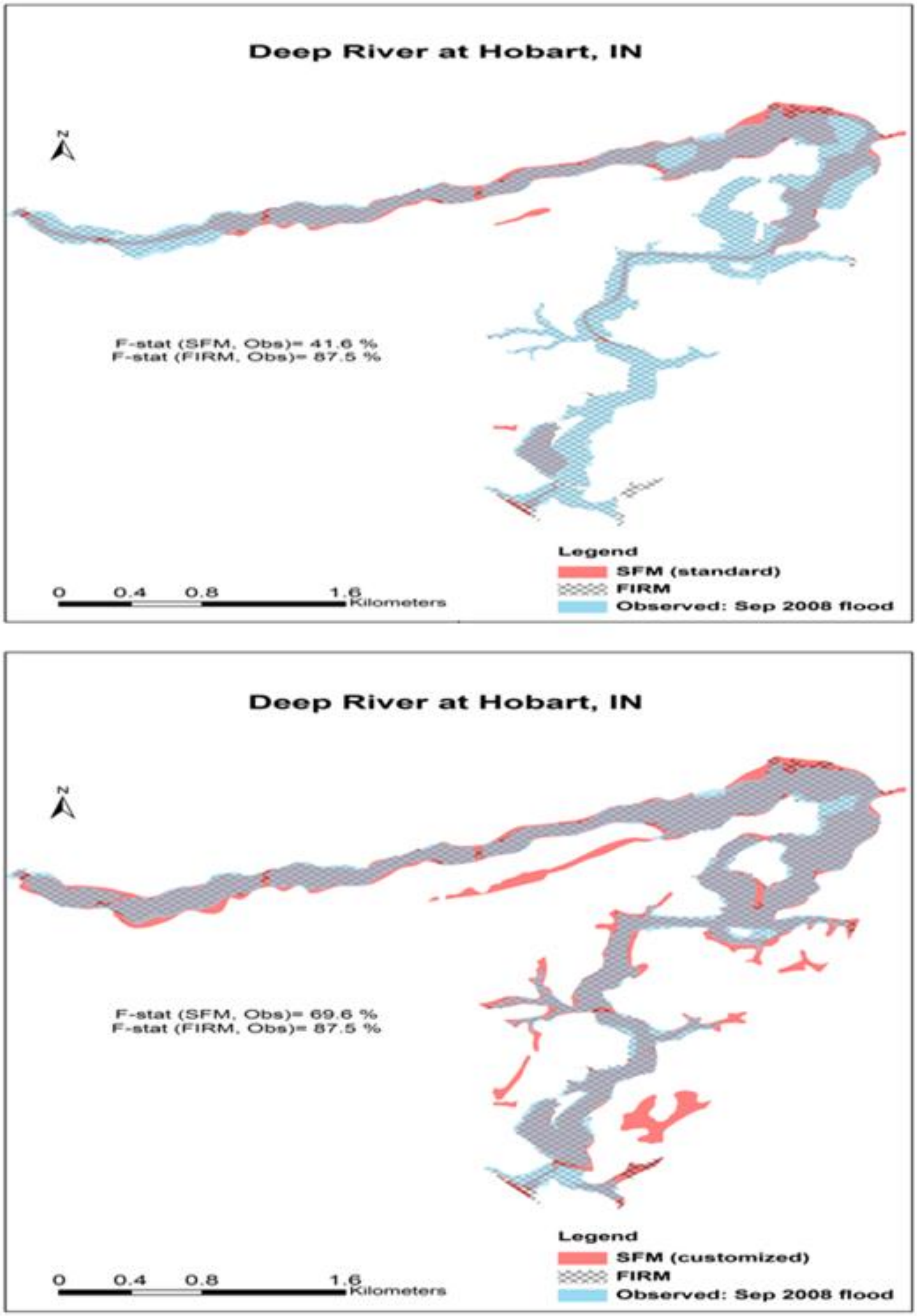


Figure 5.11: Post-customization improvement in the SFM predictions

when this additional criterion i.e. *geomorphic description= 'depressions on lake plains, outwash plains'* was applied to the other regions of Indiana, it was observed that although it improved the flood extent performance of SFMs in certain counties (especially, Johnson County) of Central Till Plain region, it had very little impact on the flood extents of SFMs in the Southern Hills and Lowlands region. One major limitation of this criterion is that it results in the inclusion of numerous, isolated depressions; thereby, giving highly over-estimated flood extents in certain counties located in the northern part of the Wabash River basin.

Finally, map units with soils formed from alluvial parent material (*pmkind* = '*Alluvium*' or '*Slope alluvium*') were also selected to explore yet another criterion for indentifying flood-prone regions. However, it was noticed that application of this criterion did not result in any additional flood extents. In other words, map units with alluvial origin soils are encompassed by the standard selection criteria.

# CHAPTER 6. SUMMARY AND CONCLUSIONS

A novel approach to floodplain mapping using SSURGO database was introduced in this study. The validation and analysis of these soil survey based floodplain maps suggest that this new approach offers an alternative flood inundation mapping technique that provides huge savings in time and cost, while being accurate enough for most practical purposes.

In general, the flood extent prediction performance of a SFM is as good as that of a flood risk map derived using DEMs. The overlap of both the maps with the regulatory standard FIRMs was found to be around 72% in the study areas located along major streams. Even when the SFMs were evaluated against the actual flood extents observed during the recent flood events in study areas, it gave similar performance (around 72% overlap). FIRMs, on the other hand, gave a better overlap with F-statistics averaging around 87%. However, this gain of 15-percentage point comes at a cost of large monetary and time investments. A typical FEMA riverine study costs around $5000 to $10,000 per mile of stream reach (FEMA, 2007), and takes weeks of surveying and mapping work. In comparison, development of SFM for an entire survey area (usually a county) virtually costs nothing, and takes only a few minutes. Thus, albeit with a slight loss in accuracy, SFMs offer a much cheaper and faster alternative for floodplain mapping.

Such economical alternative techniques have high utility, especially in the less developed areas where detailed flood studies have not yet been carried out because of budget constraints. Soil survey-based floodplain extents reach out farther into the remote areas, extending even to the first order streams. Although SFMs and FIRMs have moderately-conforming (around 59-percent overlap) flood extent predictions along these lower order creeks, SFMs are able to capture most of the FIRM extents, and thus provide a more conservative flood extent prediction. Moreover, the conformation is found to be better than in the case of DFMs. Hence, the financial constraints and the large costs associated with the detailed flood studies (like FIRMs) make the use of low-cost, albeit over-predicting, SFMs an attractive proposition in these regions.

Finally, it is important to remember here that the floodplain maps derived using SSURGO have their own limitations. These flood maps delineate the approximate floodplain extents, and are not meant to supersede the detailed flood inundation studies where they exist. Additionally, certain regions require special attention because of their unique geomorphology or land use. For instance, SFMs fail to make good predictions in certain highly urbanized areas. In general, the performance of SFMs in Northern Indiana region is much lower than in the rest of Indiana. Atypical geomorphology owing to its glacial geological history warrants different selection criteria for SFMs in this region. In fact, inclusion of selection criterion like *geomdescr='depressions on outwash plains, lake plains'* did show marked improvement in predictions. Thus, there is a need and scope for further fine-tuning the selection criteria in certain regions.

Future studies should focus on the development of SFMs for the entire country, and their customization as per the regional requirements. Errors associated with the delineation of SSURGO map units, and their impact on the accuracy of SFM flood extents also needs to be studied further. Since, topography is very fundamental to all runoff processes, future research work must focus on the integration of SFM approach with topographic approach. Floodplains can be delineated by finding appropriate threshold limits of terrain attributes such as Multi-Resolution Valley Bottom Flatness index or Wetness index. These indices, in turn, can be derived from a DEM. Integration of any such topography-based approach with the SFM approach promises to be an effective, yet inexpensive floodplain mapping technique.

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APPENDICES

# Appendix A Floodplain maps of entire Indiana state

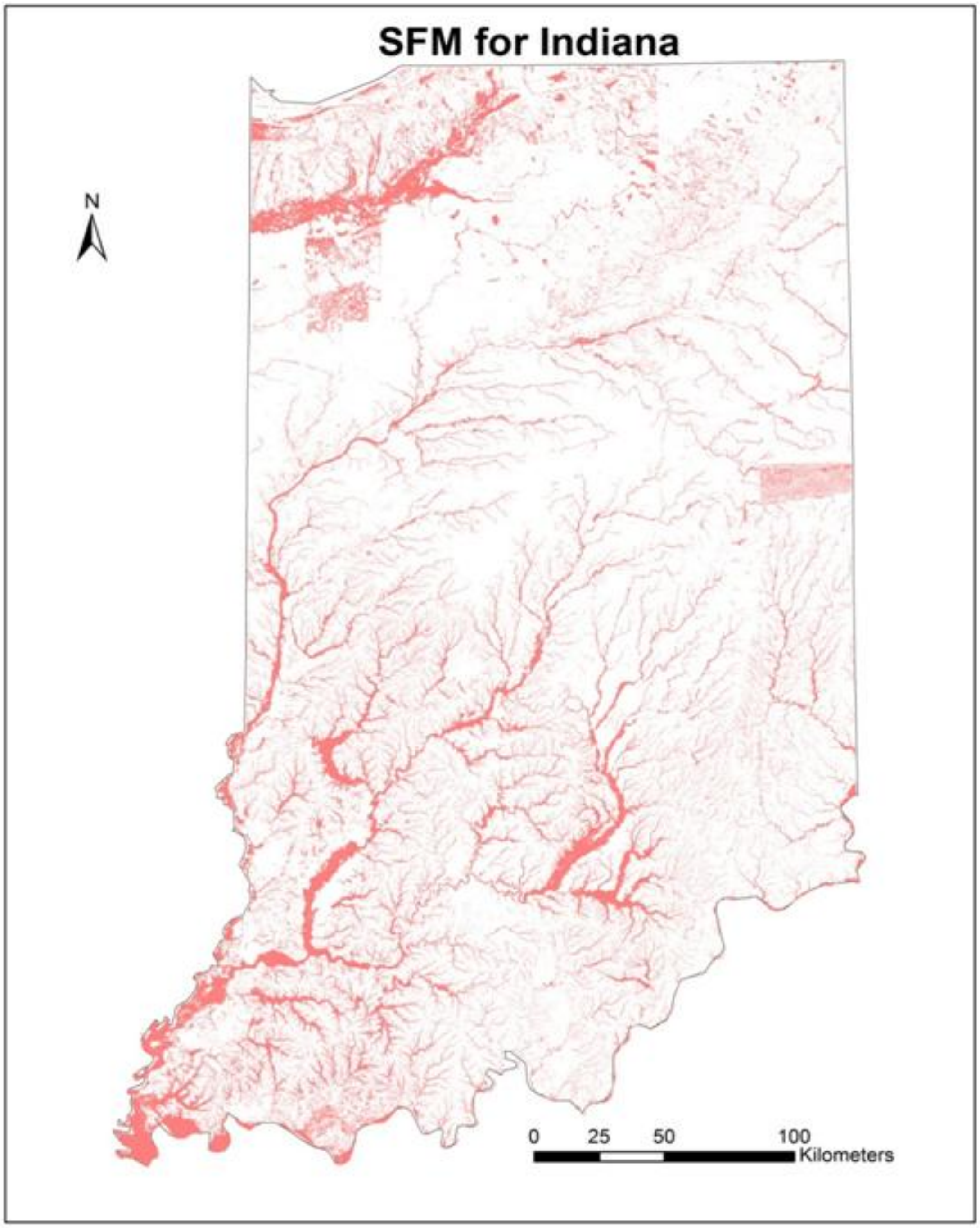



Figure A.1: SSURGO based floodplain map for entire Indiana

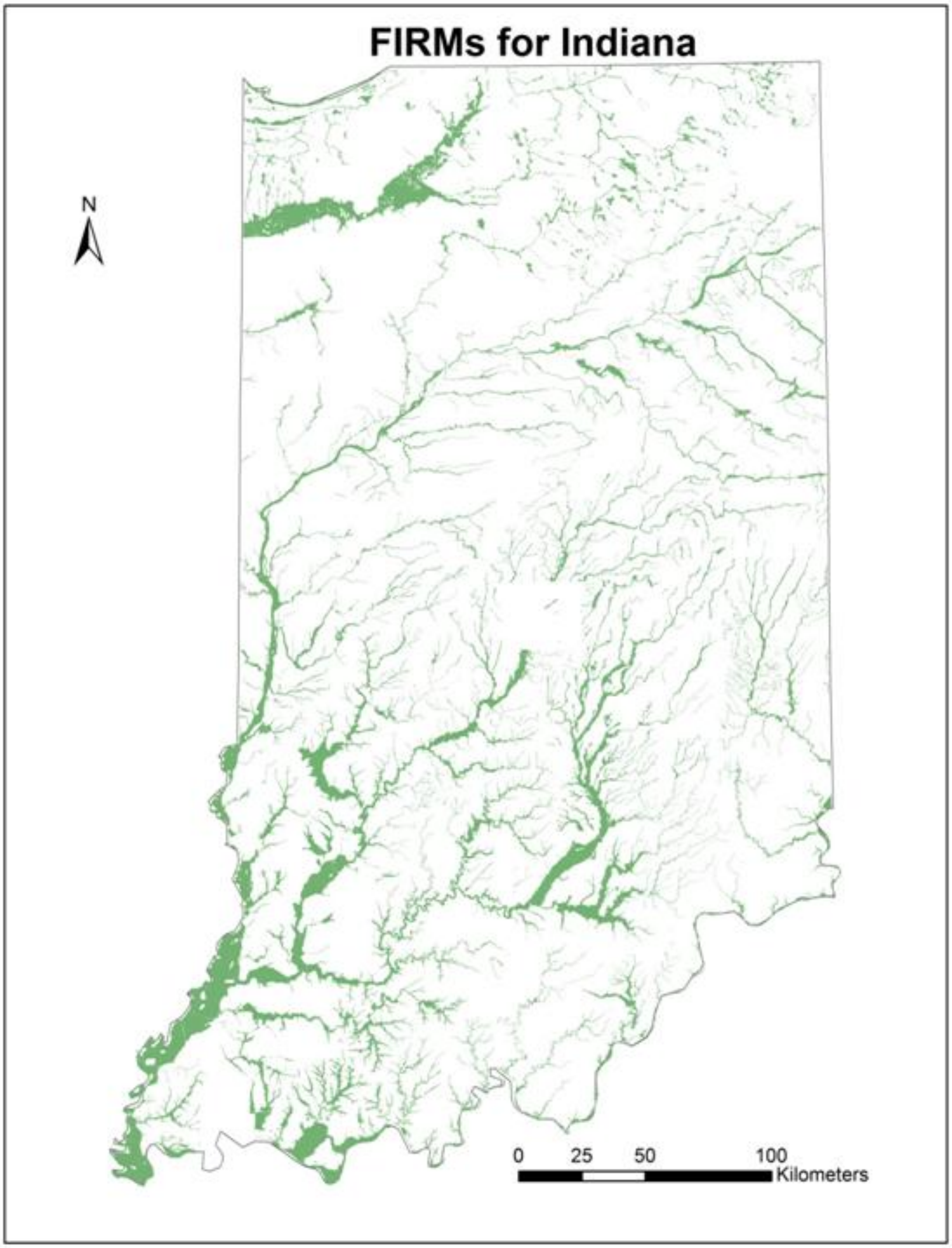



Figure A.2: FEMA issued flood insurance rate maps (FIRMs) for entire Indiana

Appendix B Floodplain maps near OHRFC stations

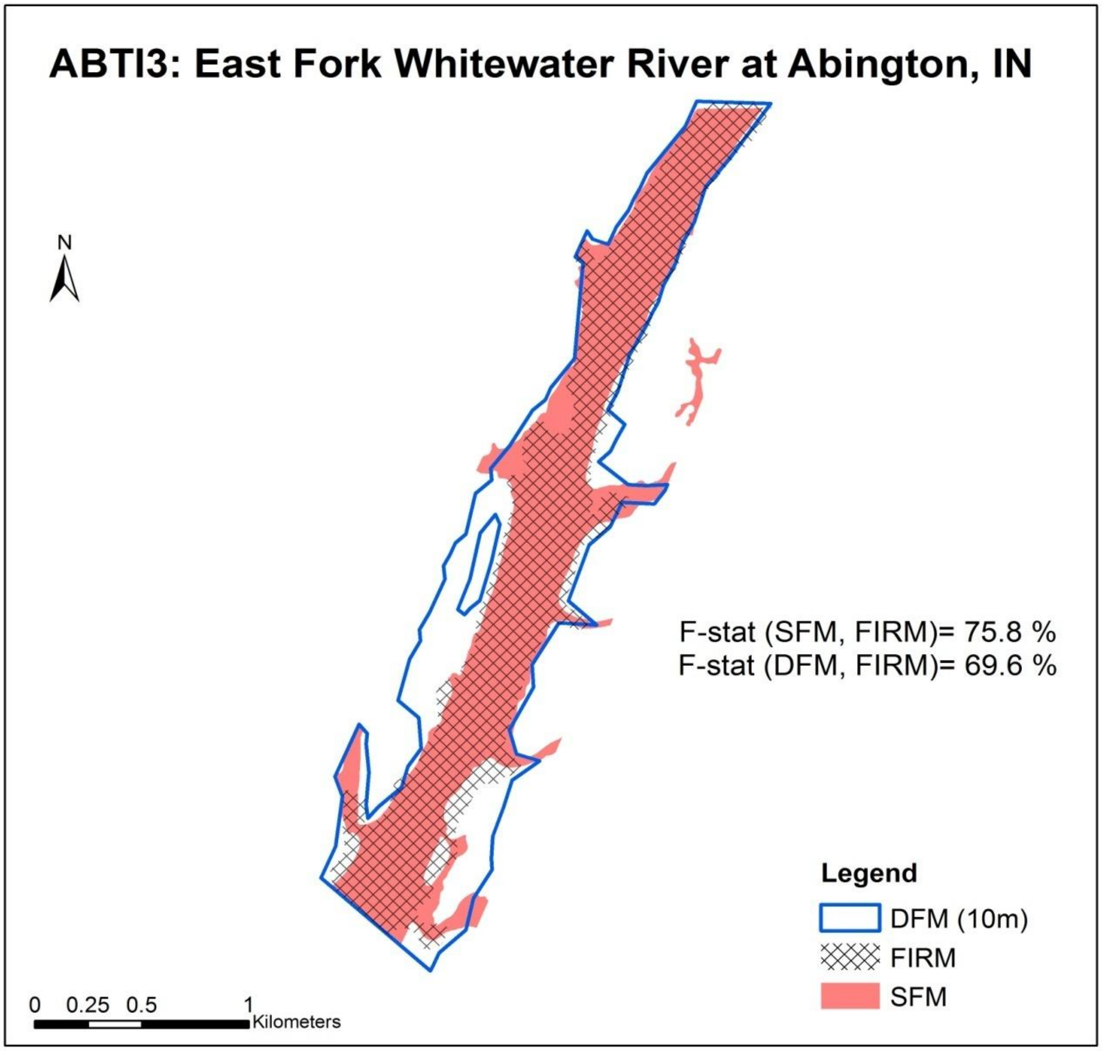



Figure B.1

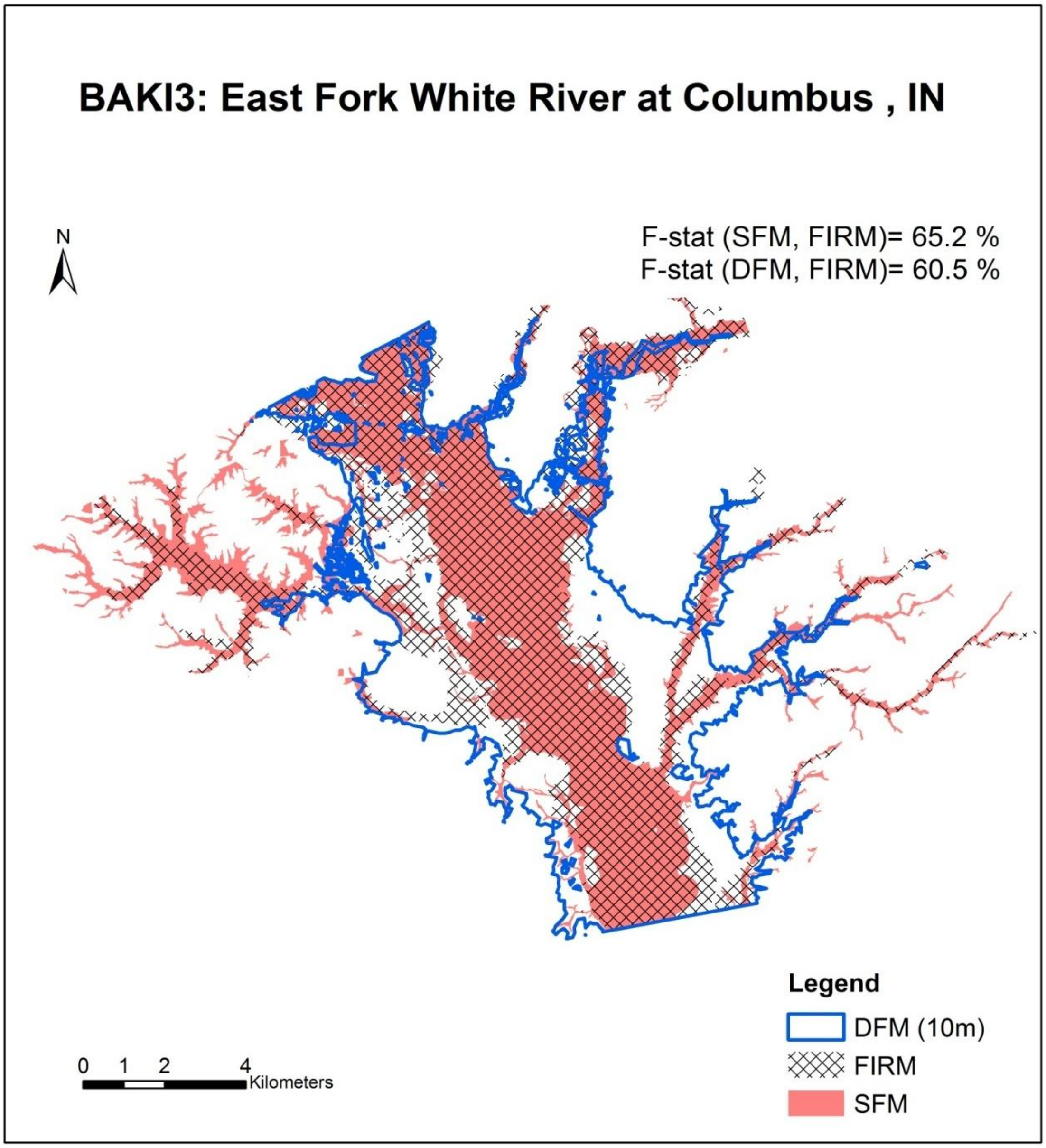
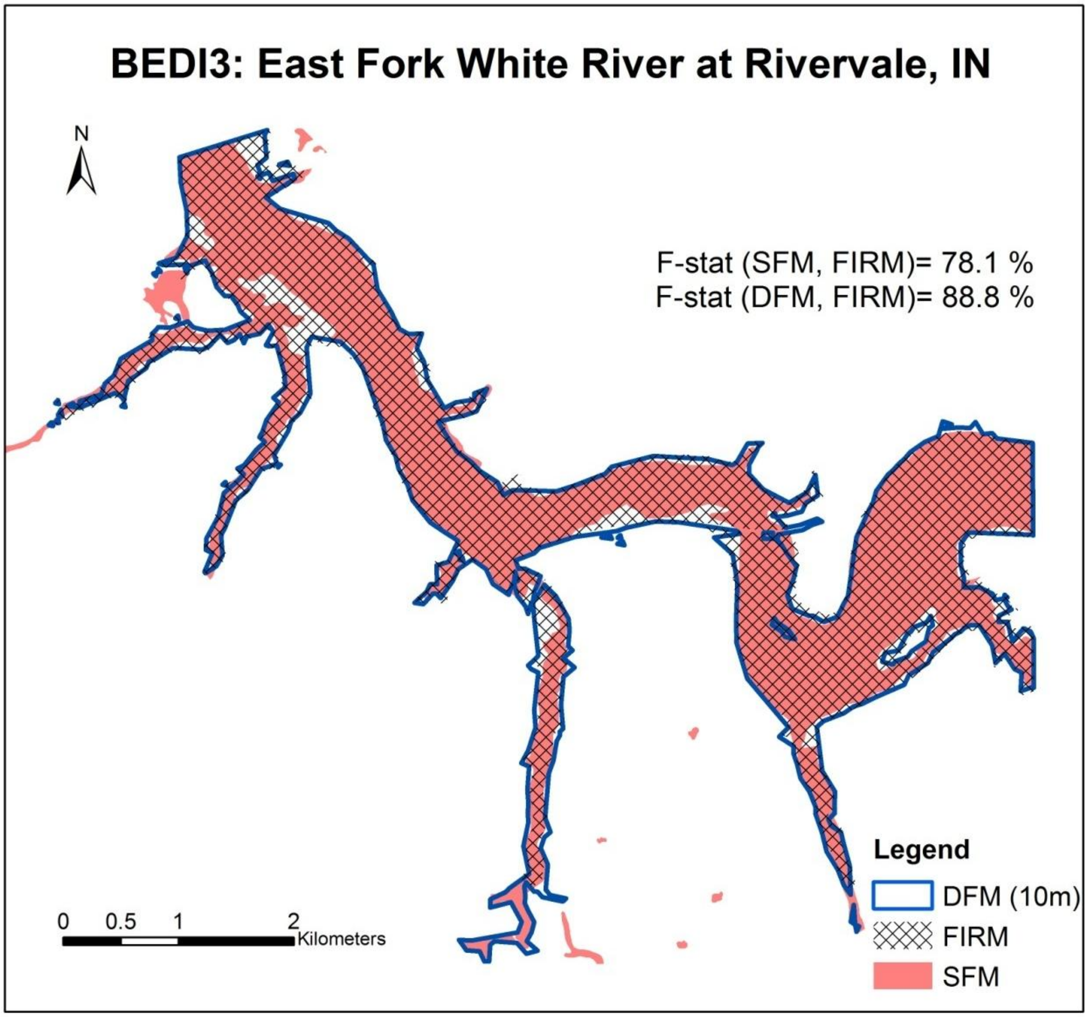

BAKI3: East Fork White River at Columbus , IN
N
F-stat (SFM, FIRM)= 65.2 %
F-stat (DFM, FIRM)= 60.5 %
Legend
DFM (10m)
FIRM
SFM
0 1 2 4
Kilometers

Figure B.2



BEDI3: East Fork White River at Rivervale, IN
N
F-stat (SFM, FIRM)= 78.1 %
F-stat (DFM, FIRM)= 88.8 %
0 0.5 1 2
Kilometers
Legend
DFM (10m)
FIRM
SFM


Figure B.3

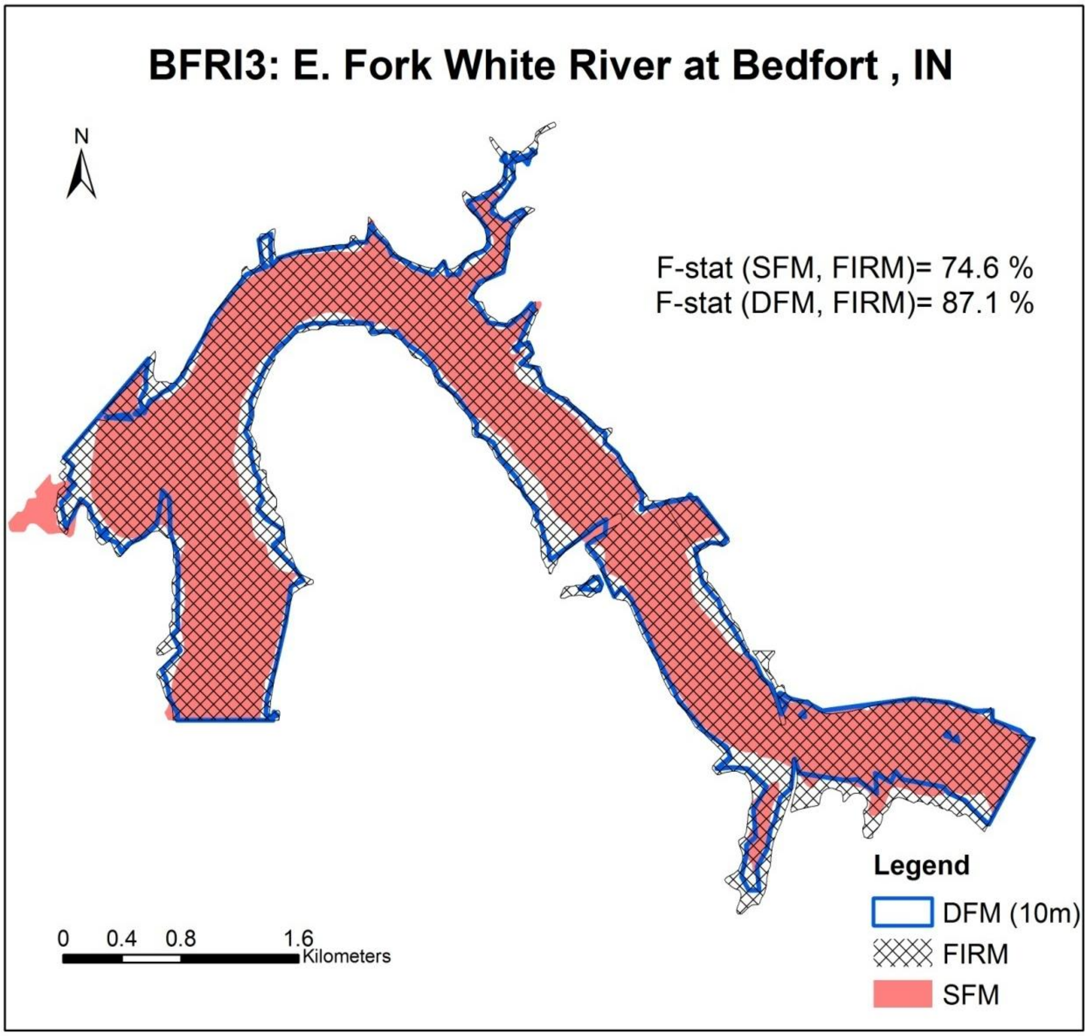

BFRI3: E. Fork White River at Bedfort , IN
N
F-stat (SFM, FIRM)= 74.6 %
F-stat (DFM, FIRM)= 87.1 %
0 0.4 0.8 1.6
Kilometers
Legend
DFM (10m)
FIRM
SFM

Figure B.4

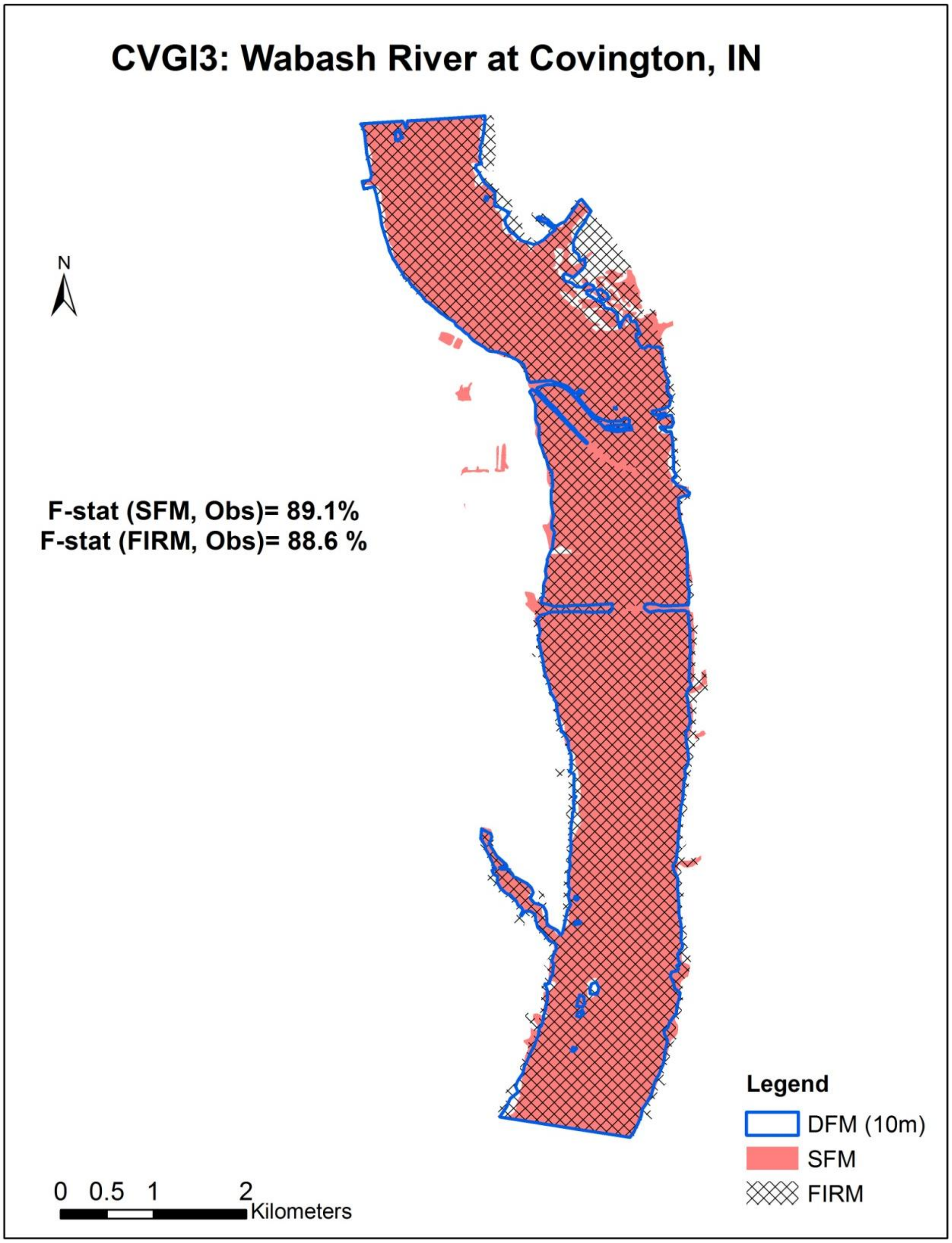

CVGI3: Wabash River at Covington, IN
N
F-stat (SFM, Obs)= 89.1%
F-stat (FIRM, Obs)= 88.6 %
Legend
DFM (10m)
SFM
FIRM
0 0.5 1 2
Kilometers

Figure B.5

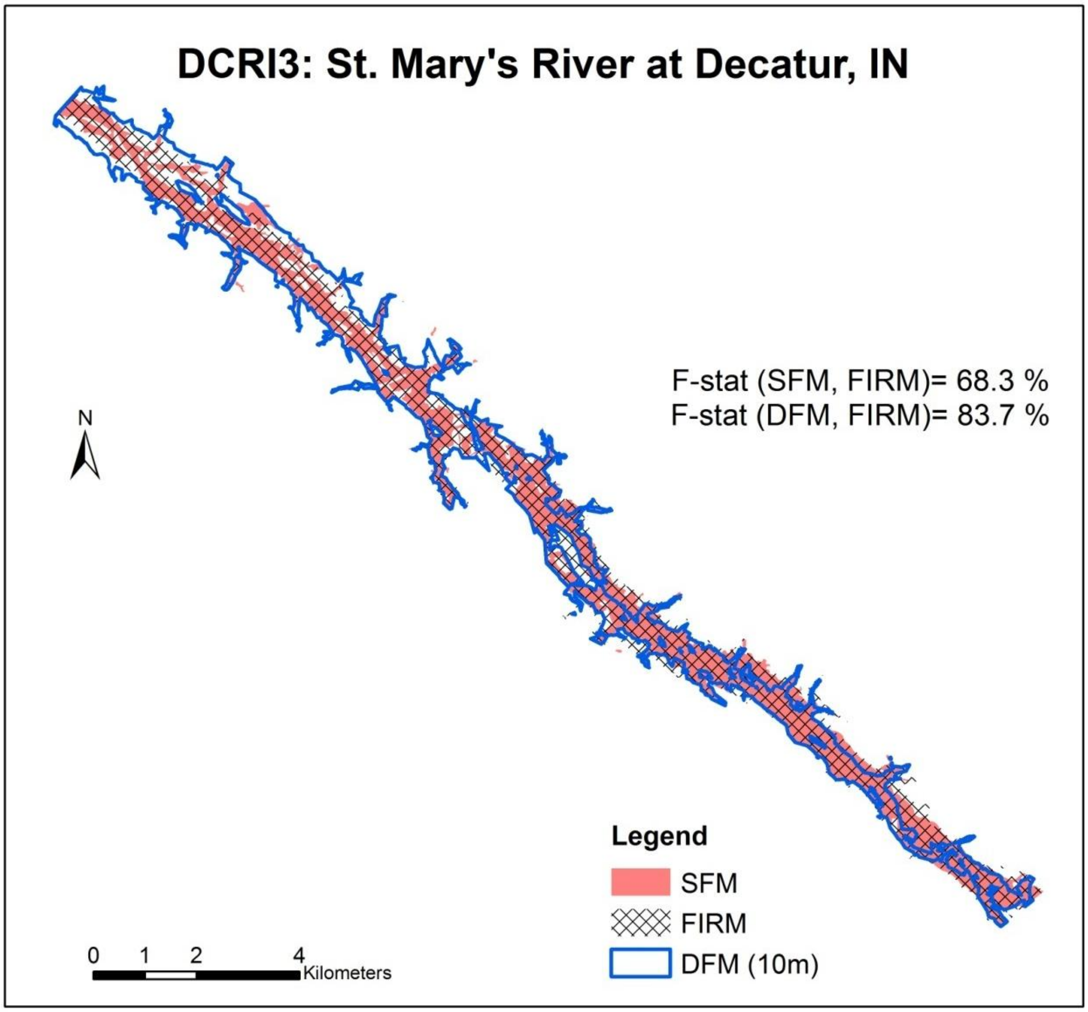

DCRI3: St. Mary's River at Decatur, IN
F-stat (SFM, FIRM)= 68.3 %
F-stat (DFM, FIRM)= 83.7 %
N
Legend
SFM
FIRM
DFM (10m)
0 1 2 4 Kilometers

Figure B.6

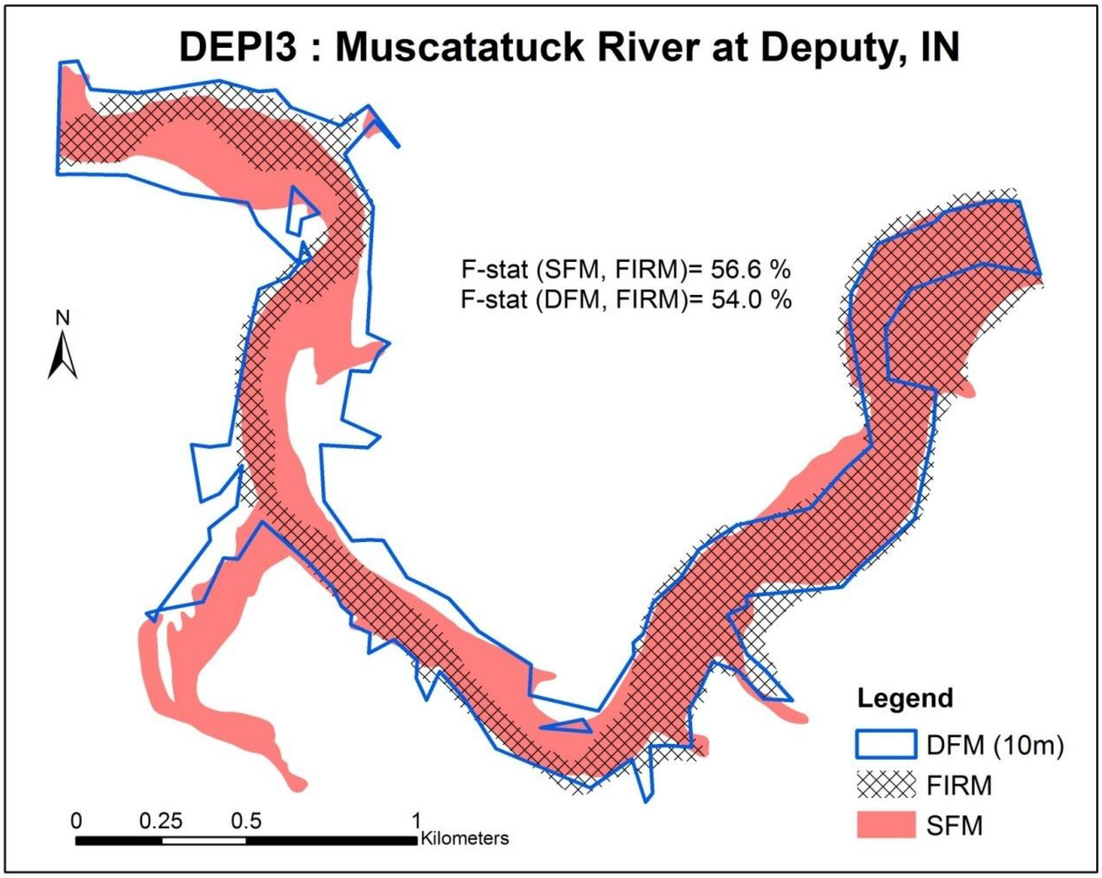

DEPI3 : Muscatatuck River at Deputy, IN
F-stat (SFM, FIRM)= 56.6 %
F-stat (DFM, FIRM)= 54.0 %
N
0
0.25
0.5
1
Kilometers
Legend
DFM (10m)
FIRM
SFM

Figure B.7

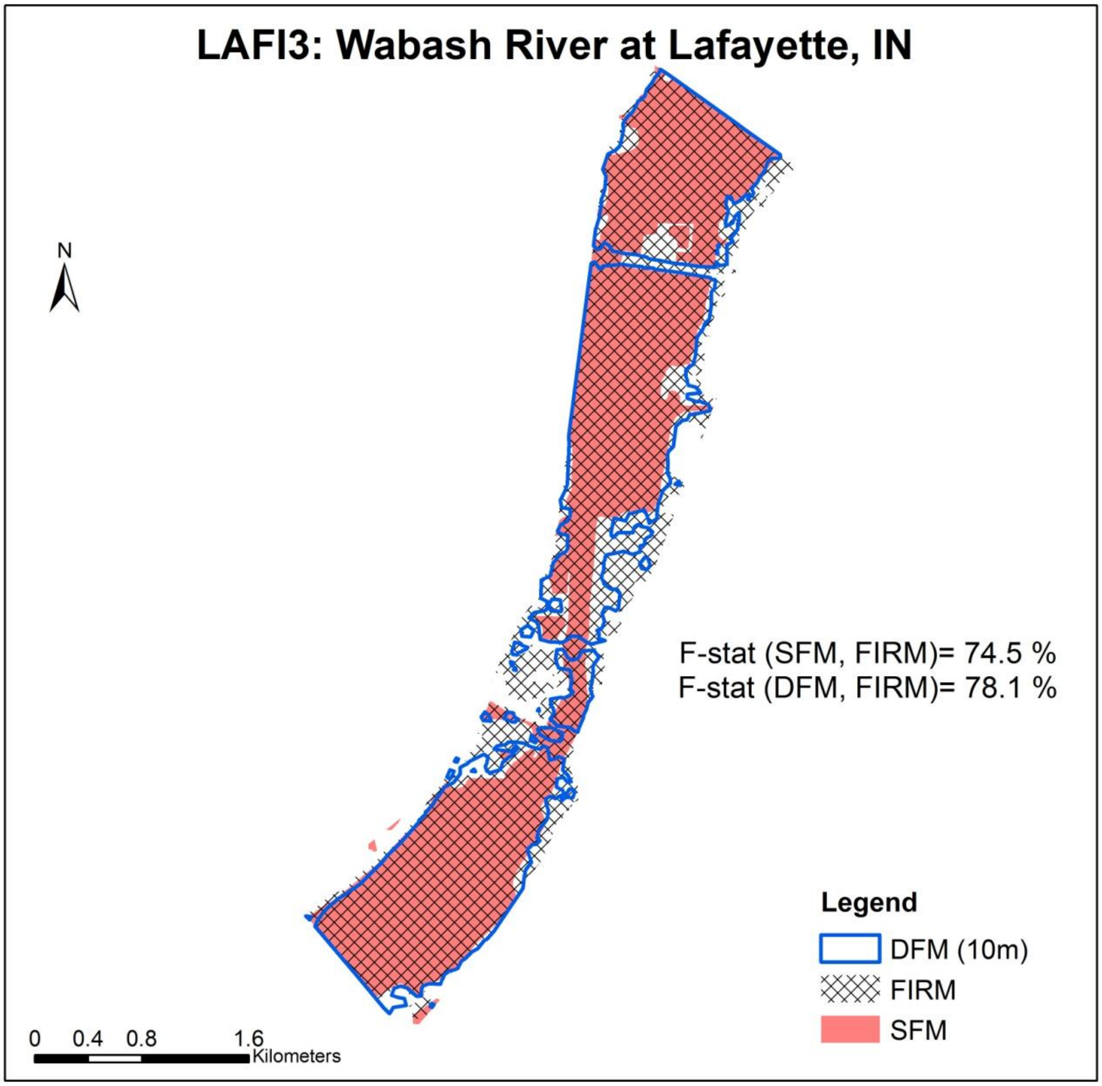

LAFI3: Wabash River at Lafayette, IN
N
F-stat (SFM, FIRM)= 74.5 %
F-stat (DFM, FIRM)= 78.1 %
Legend
DFM (10m)
FIRM
SFM
0 0.4 0.8 1.6
Kilometers

Figure B.8

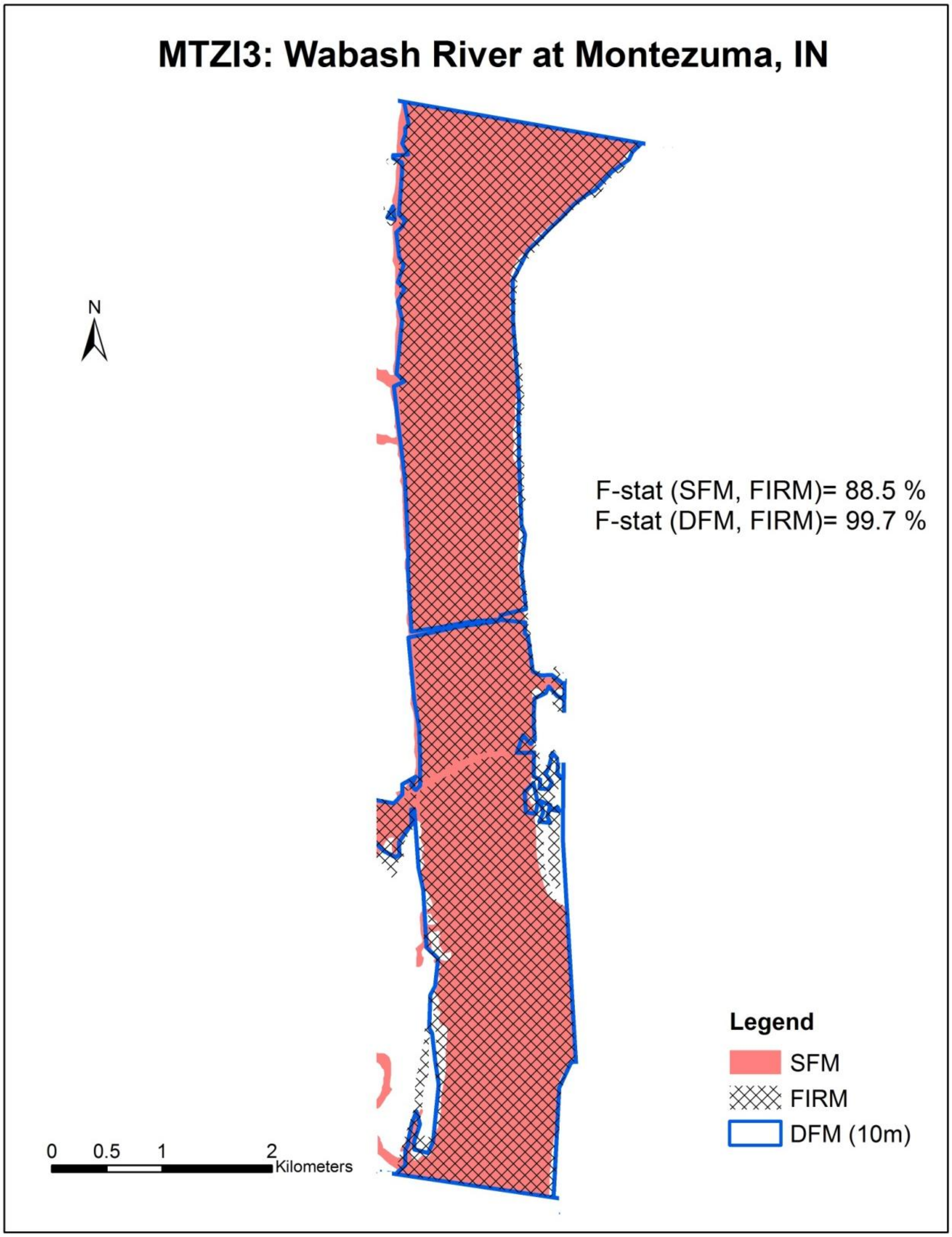

MTZI3: Wabash River at Montezuma, IN
N
F-stat (SFM, FIRM)= 88.5 %
F-stat (DFM, FIRM)= 99.7 %
Legend
SFM
FIRM
DFM (10m)
0 0.5 1 2
Kilometers

Figure B.9

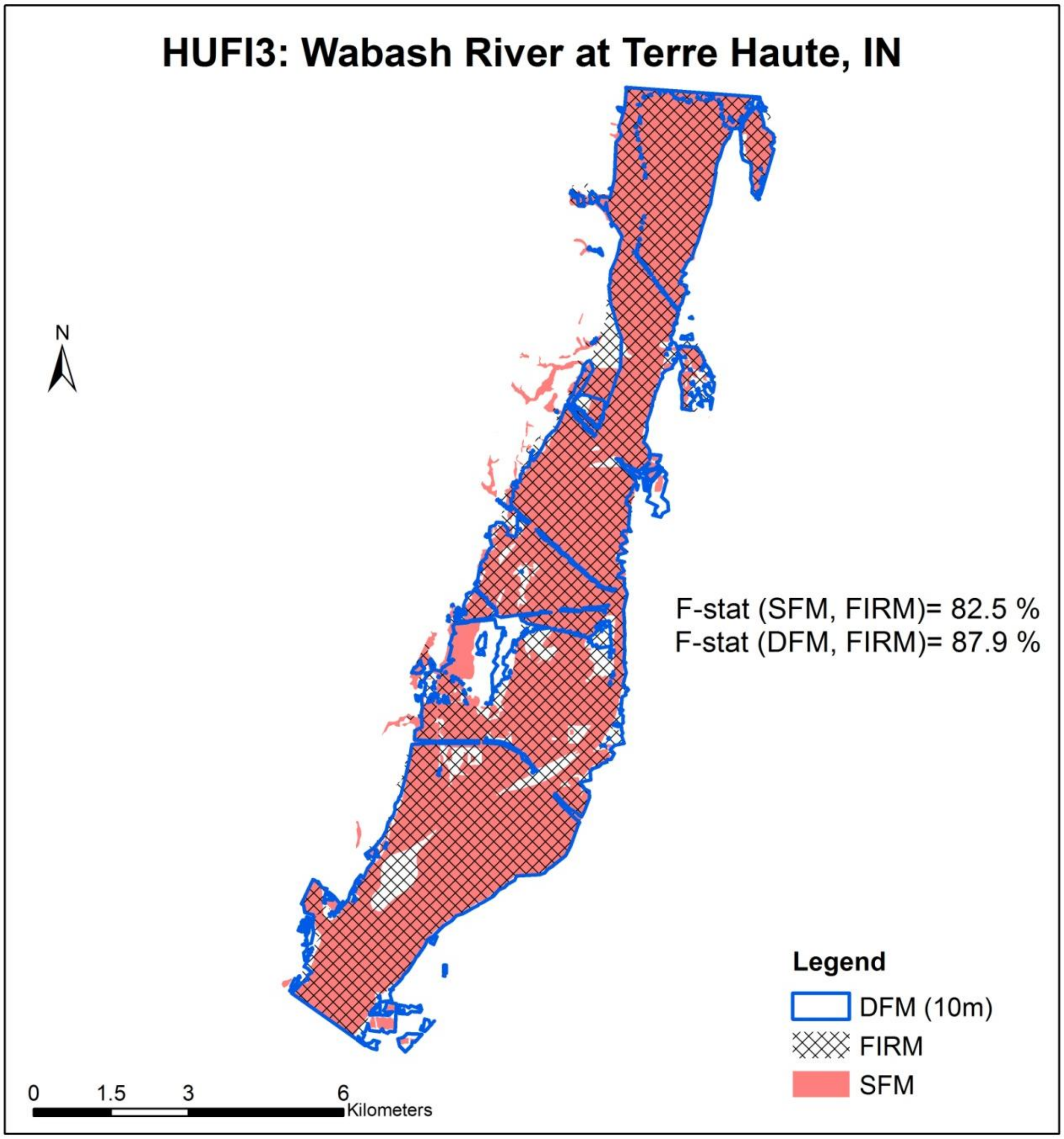

HUFI3: Wabash River at Terre Haute, IN
N
F-stat (SFM, FIRM)= 82.5 %
F-stat (DFM, FIRM)= 87.9 %
Legend
DFM (10m)
FIRM
SFM
0 1.5 3 6
Kilometers

Figure B.10

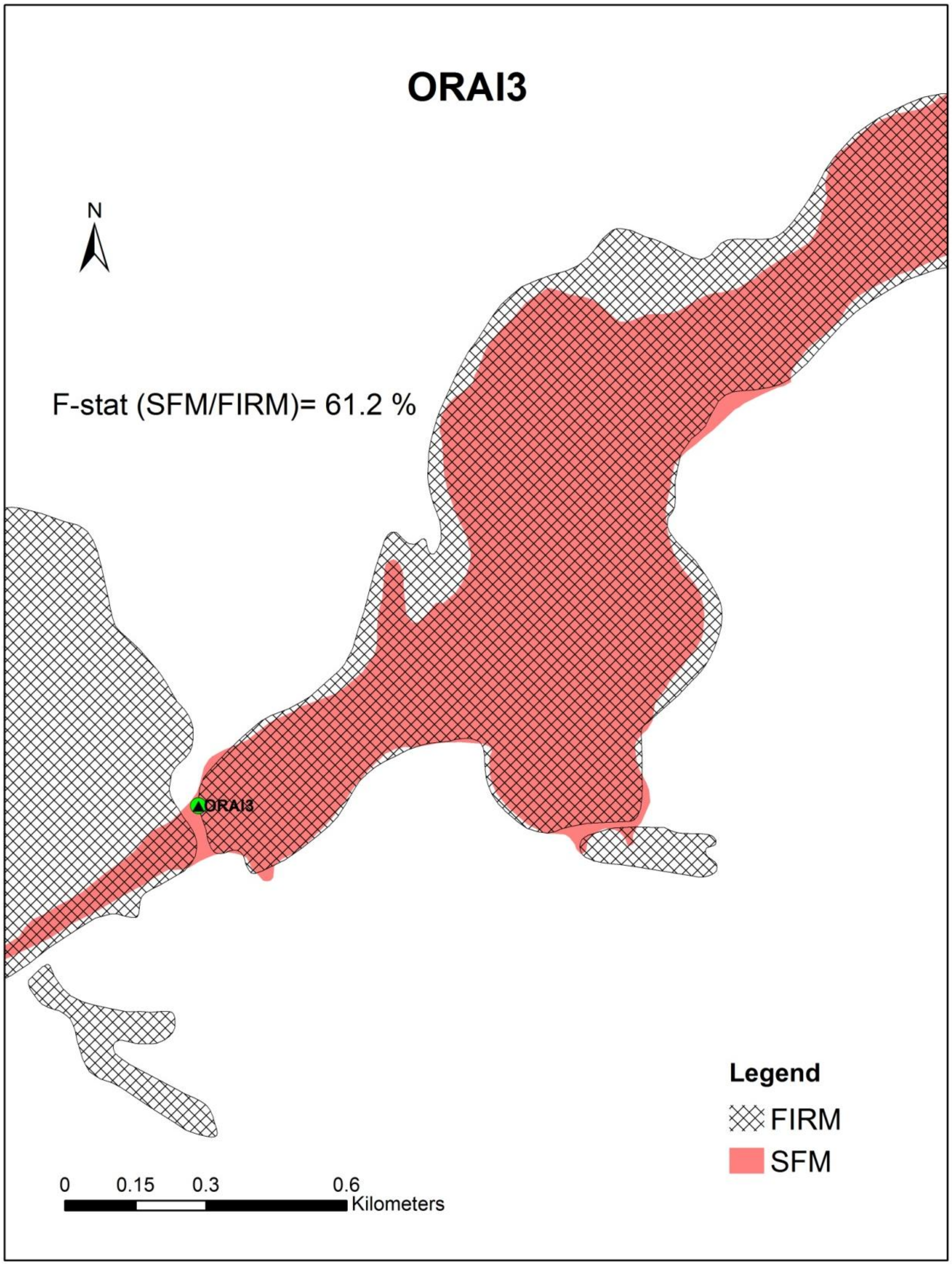

ORAI3
N
F-stat (SFM/FIRM)= 61.2 %
ORAI3
Legend
FIRM
SFM
0
0.15
0.3
0.6
Kilometers

Figure B.11

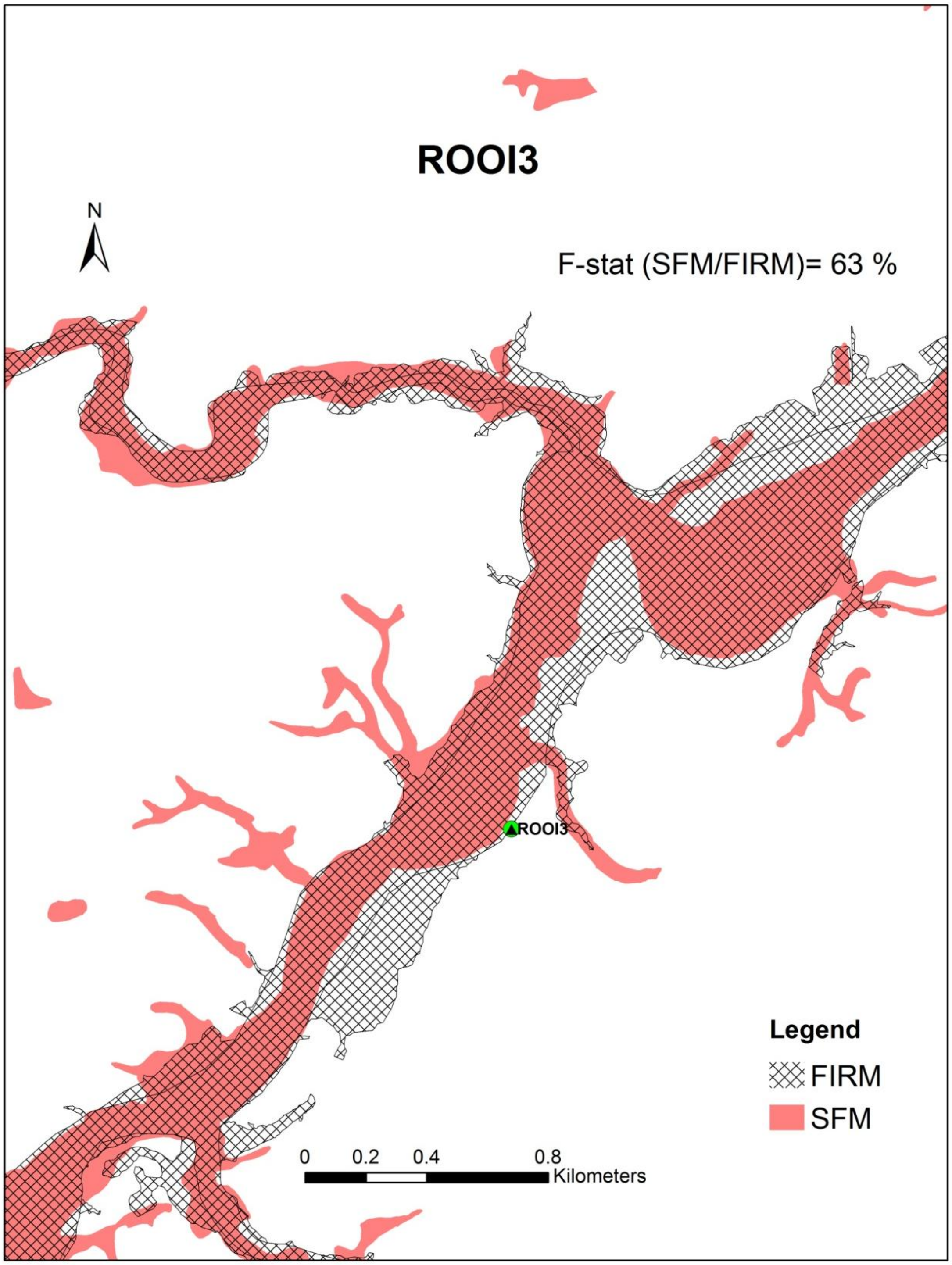

ROOI3
N
F-stat (SFM/FIRM)= 63 %
ROOI3
Legend
FIRM
SFM
0 0.2 0.4 0.8
Kilometers

Figure B.12

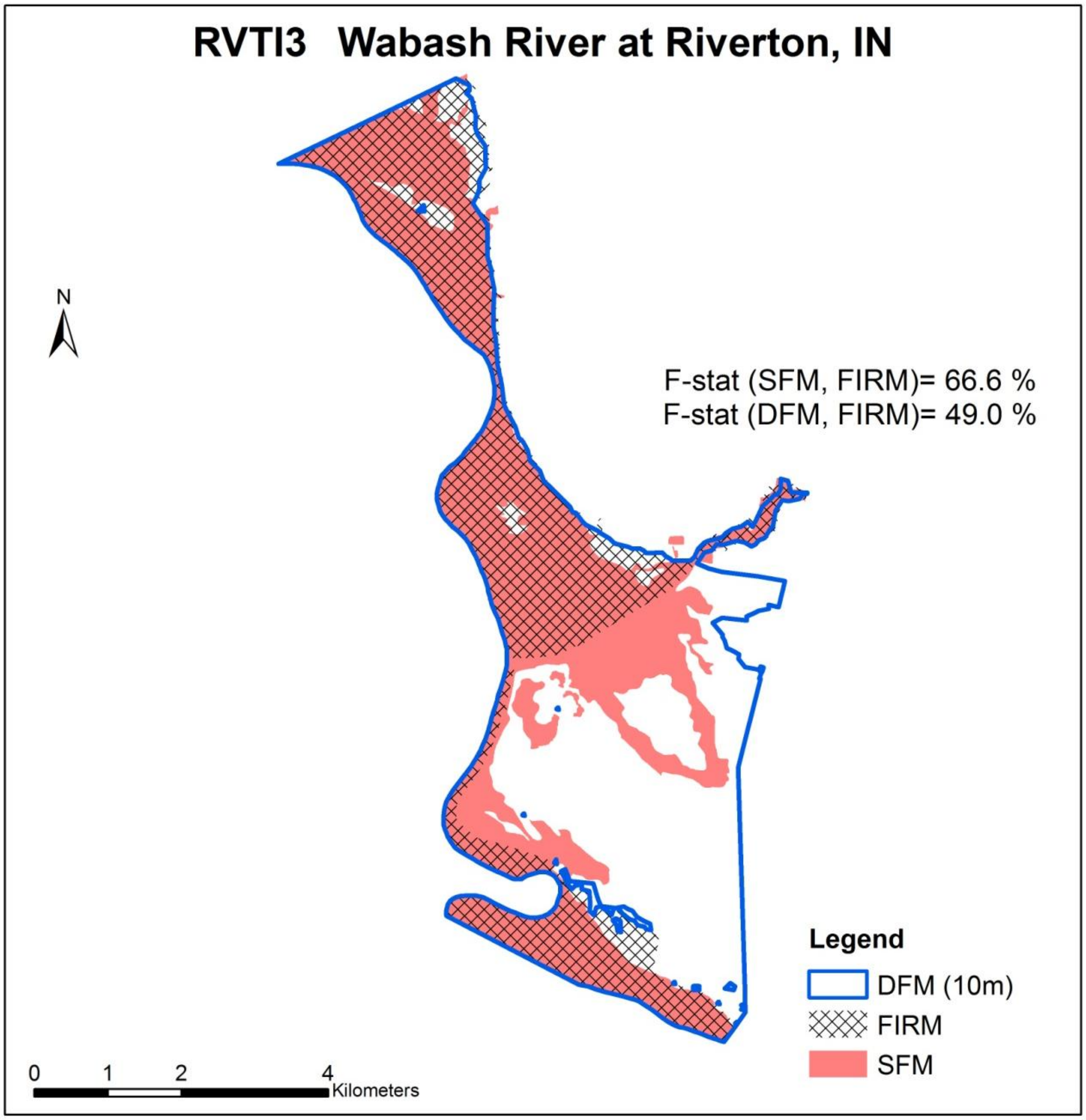

RVTI3 Wabash River at Riverton, IN
N
F-stat (SFM, FIRM)= 66.6 %
F-stat (DFM, FIRM)= 49.0 %
Legend
DFM (10m)
FIRM
SFM
0
1
2
4
Kilometers

Figure B.13

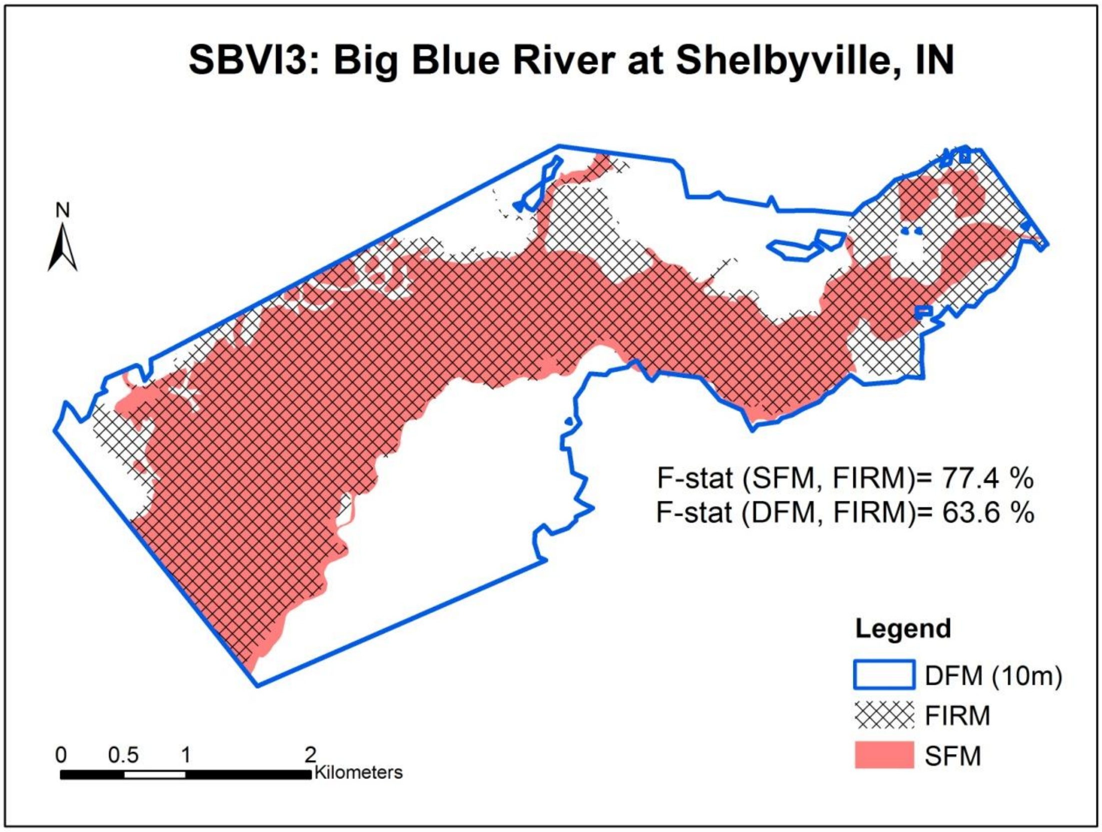

SBVI3: Big Blue River at Shelbyville, IN
N
F-stat (SFM, FIRM)= 77.4 %
F-stat (DFM, FIRM)= 63.6 %
Legend
DFM (10m)
FIRM
SFM
0 0.5 1 2
Kilometers

Figure B.14

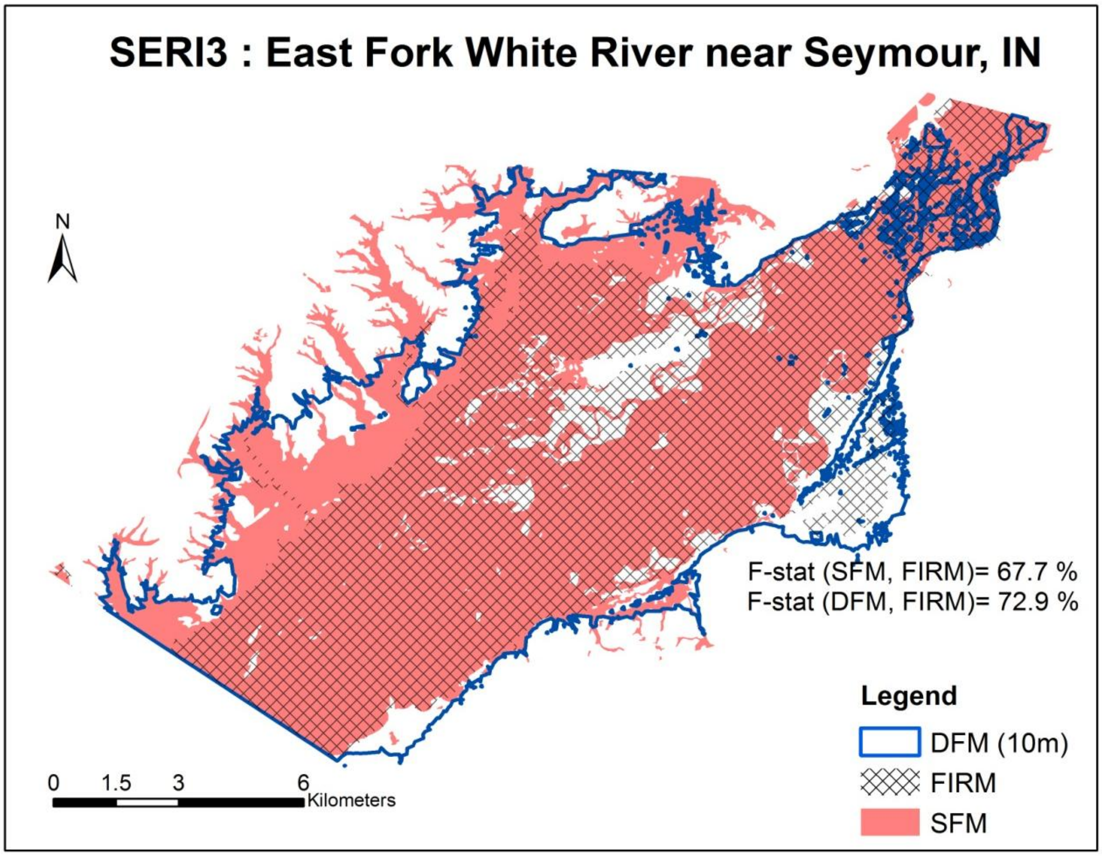

SERI3 : East Fork White River near Seymour, IN
N
F-stat (SFM, FIRM)= 67.7 %
F-stat (DFM, FIRM)= 72.9 %
0 1.5 3 6
Kilometers
Legend
DFM (10m)
FIRM
SFM

Figure B.15

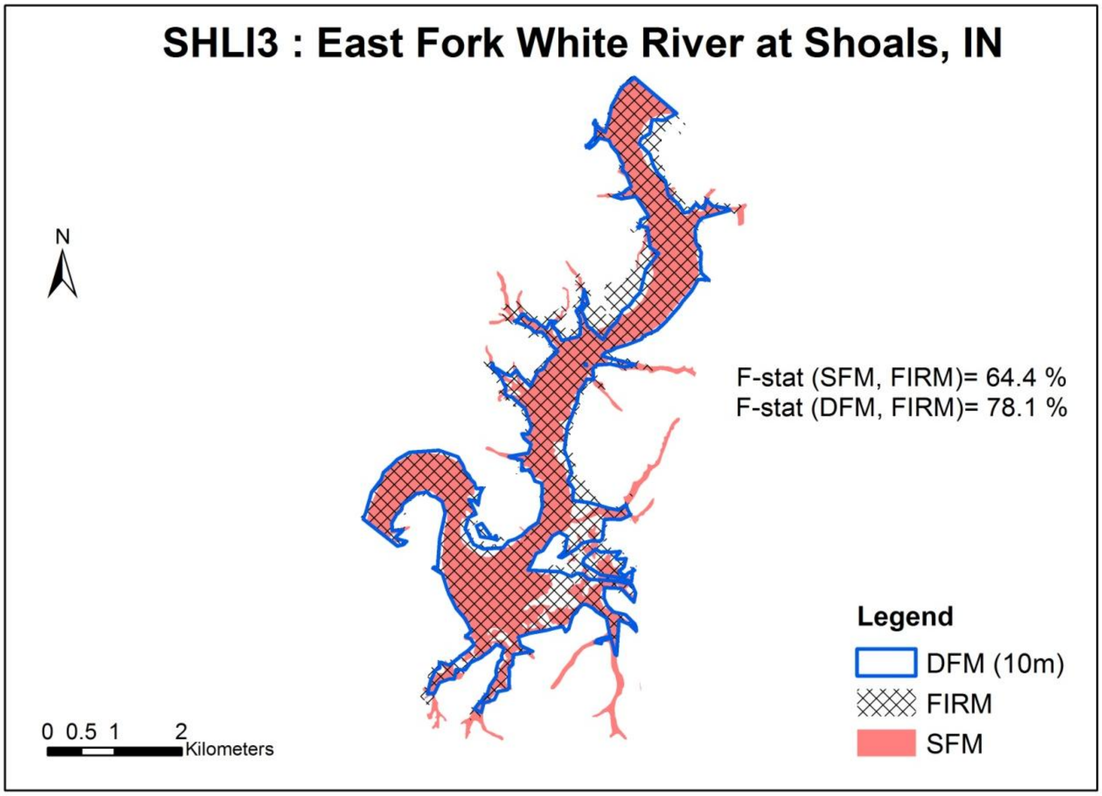

SHLI3 : East Fork White River at Shoals, IN
N
F-stat (SFM, FIRM)= 64.4 %
F-stat (DFM, FIRM)= 78.1 %
Legend
DFM (10m)
FIRM
SFM
0 0.5 1 2
Kilometers

Figure B.16

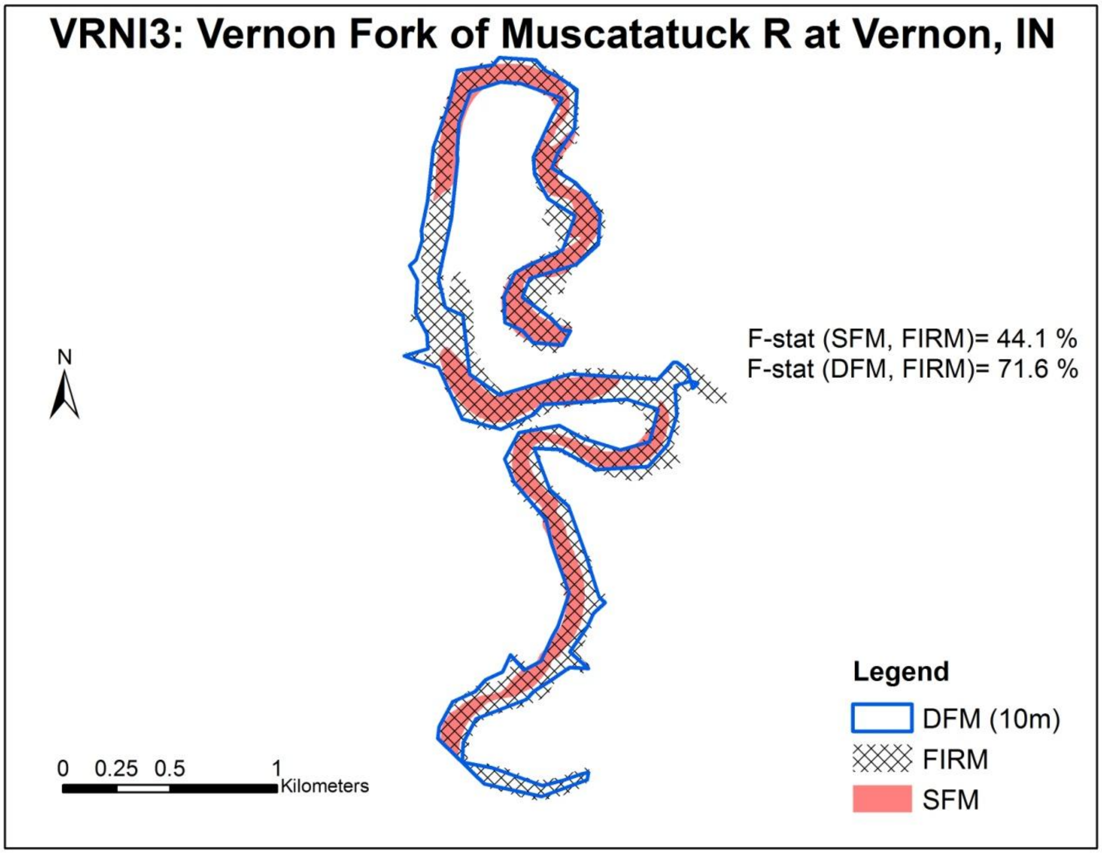

VRNI3: Vernon Fork of Muscatatuck R at Vernon, IN
N
F-stat (SFM, FIRM)= 44.1 %
F-stat (DFM, FIRM)= 71.6 %
0 0.25 0.5 1
Kilometers
Legend
DFM (10m)
FIRM
SFM

Figure B.17

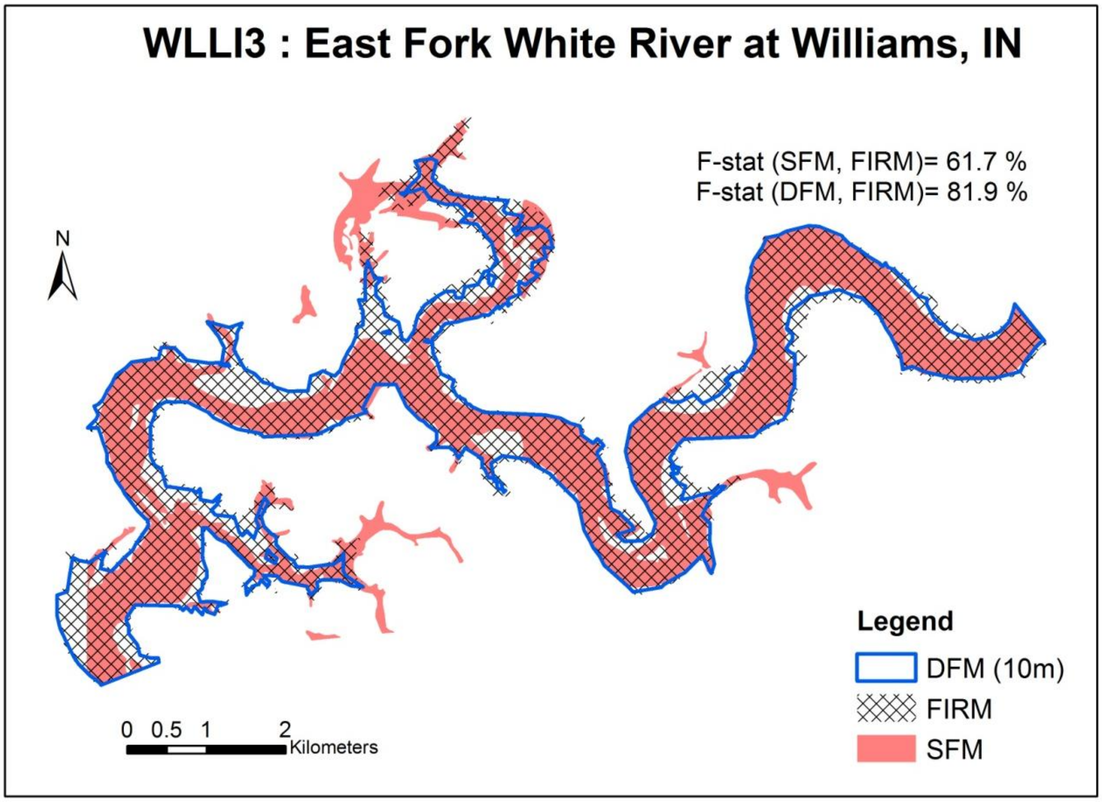

WLLI3 : East Fork White River at Williams, IN
F-stat (SFM, FIRM)= 61.7 %
F-stat (DFM, FIRM)= 81.9 %
N
0 0.5 1 2
Kilometers
Legend
DFM (10m)
FIRM
SFM

Figure B.18

Appendix C Floodplain maps and the observed flood extents

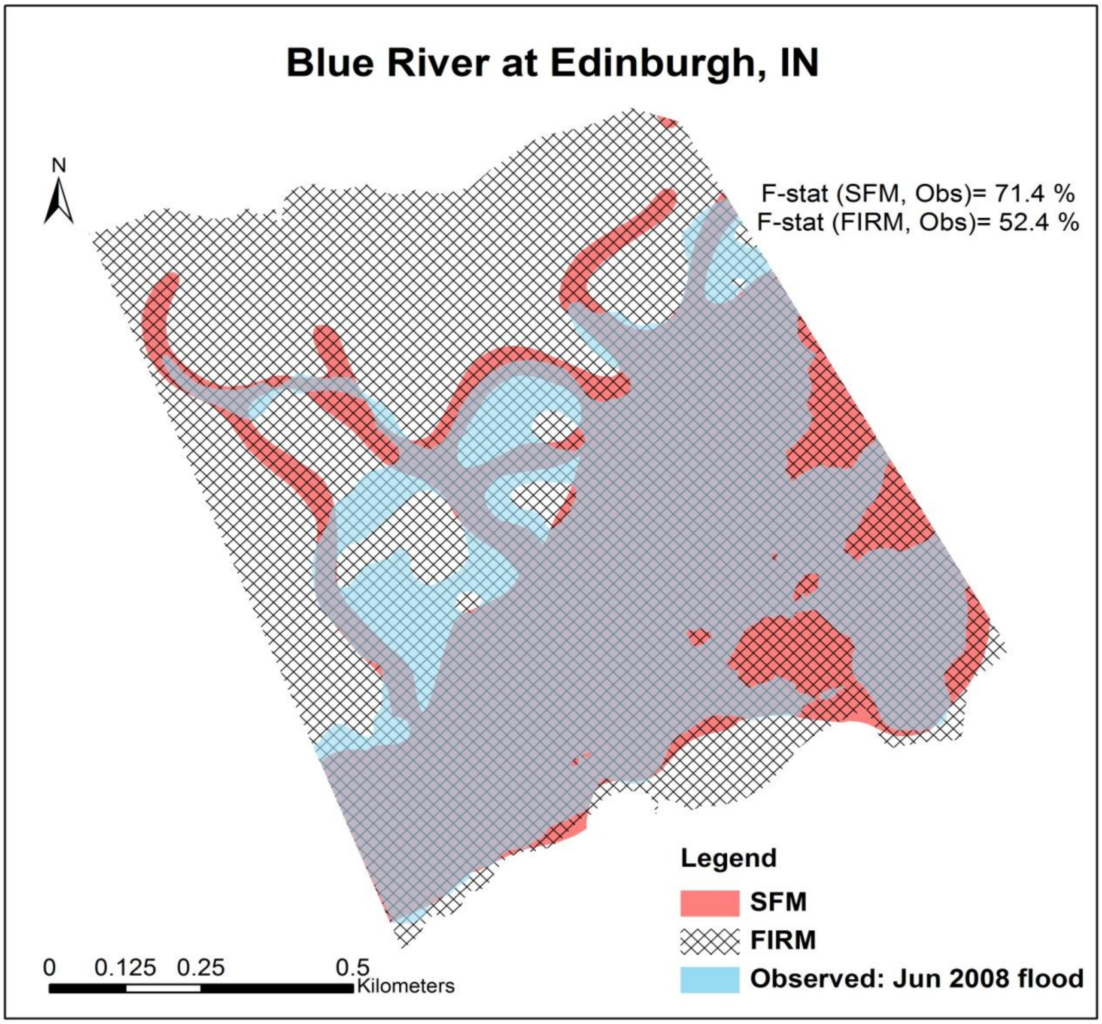



Figure C.1

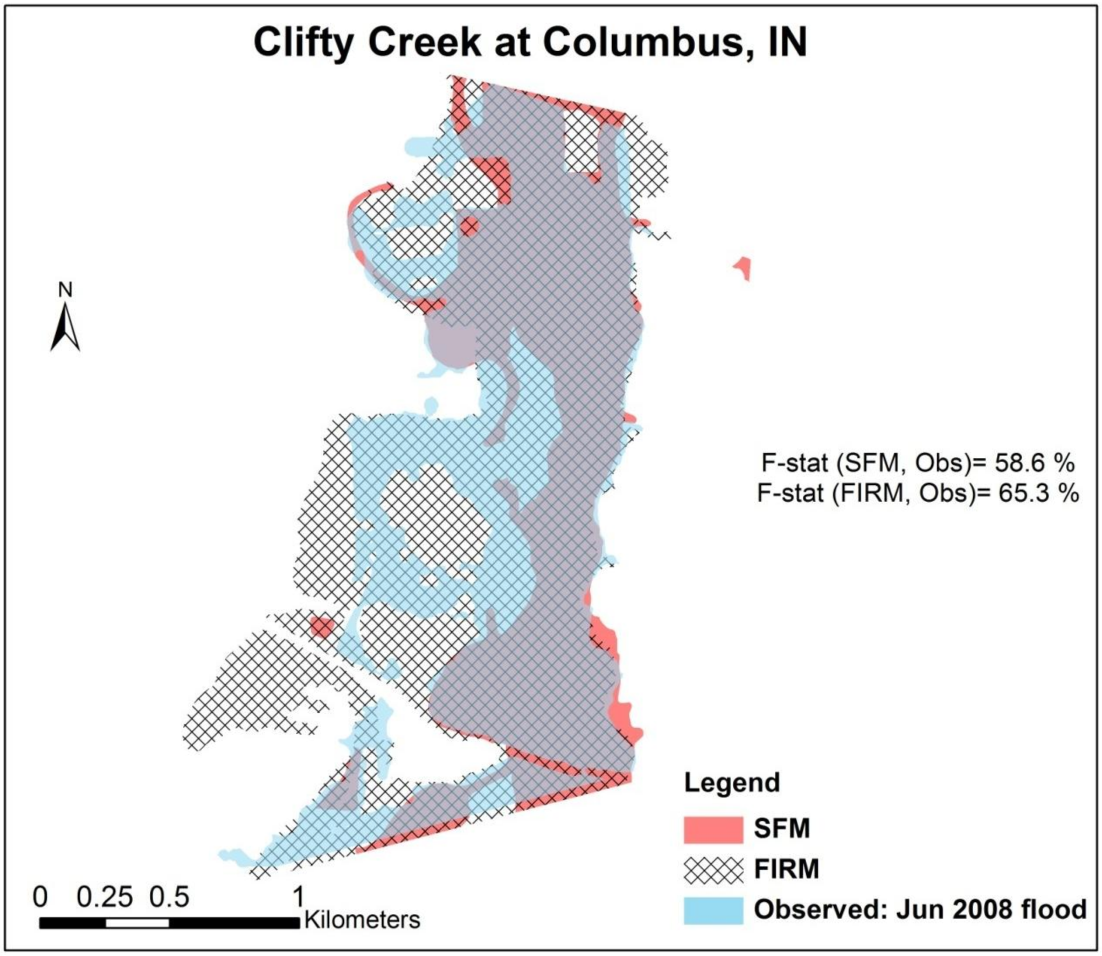

Clifty Creek at Columbus, IN
N
F-stat (SFM, Obs)= 58.6 %
F-stat (FIRM, Obs)= 65.3 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.25 0.5 1
Kilometers

Figure C.2

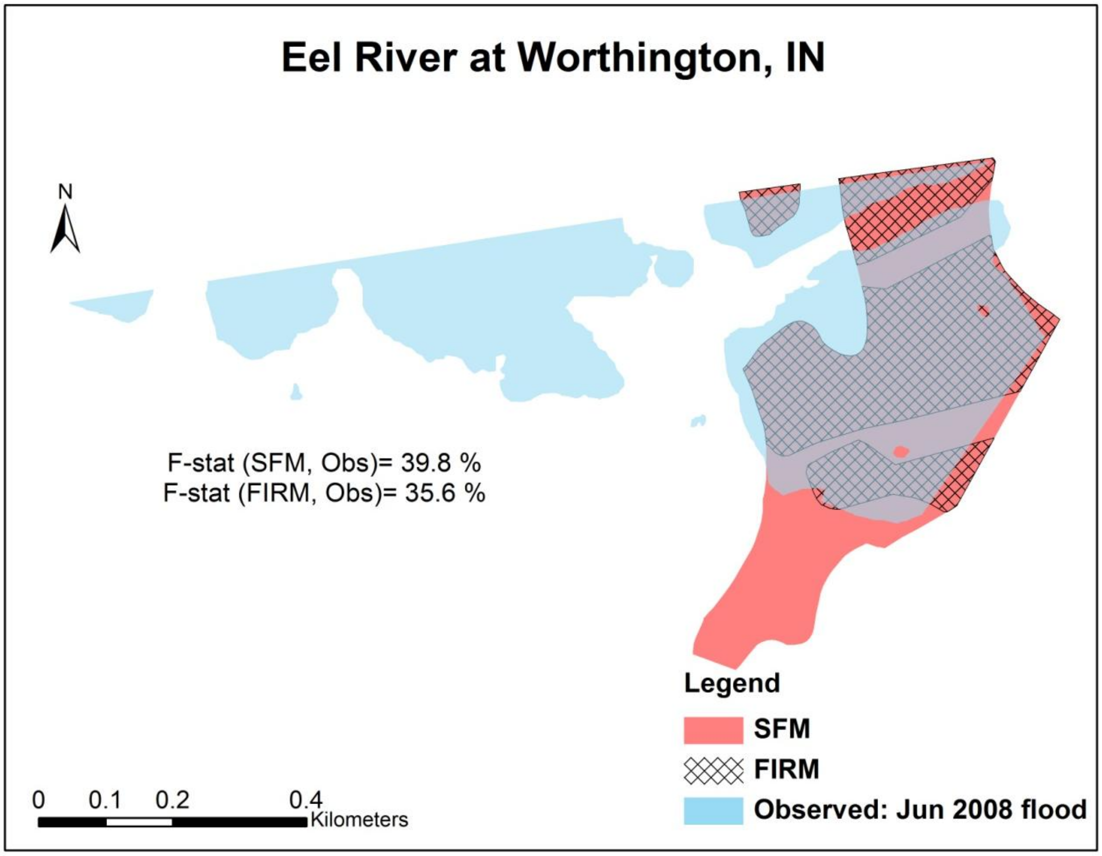

Eel River at Worthington, IN
N
F-stat (SFM, Obs)= 39.8 %
F-stat (FIRM, Obs)= 35.6 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.1 0.2 0.4
Kilometers

Figure C.3

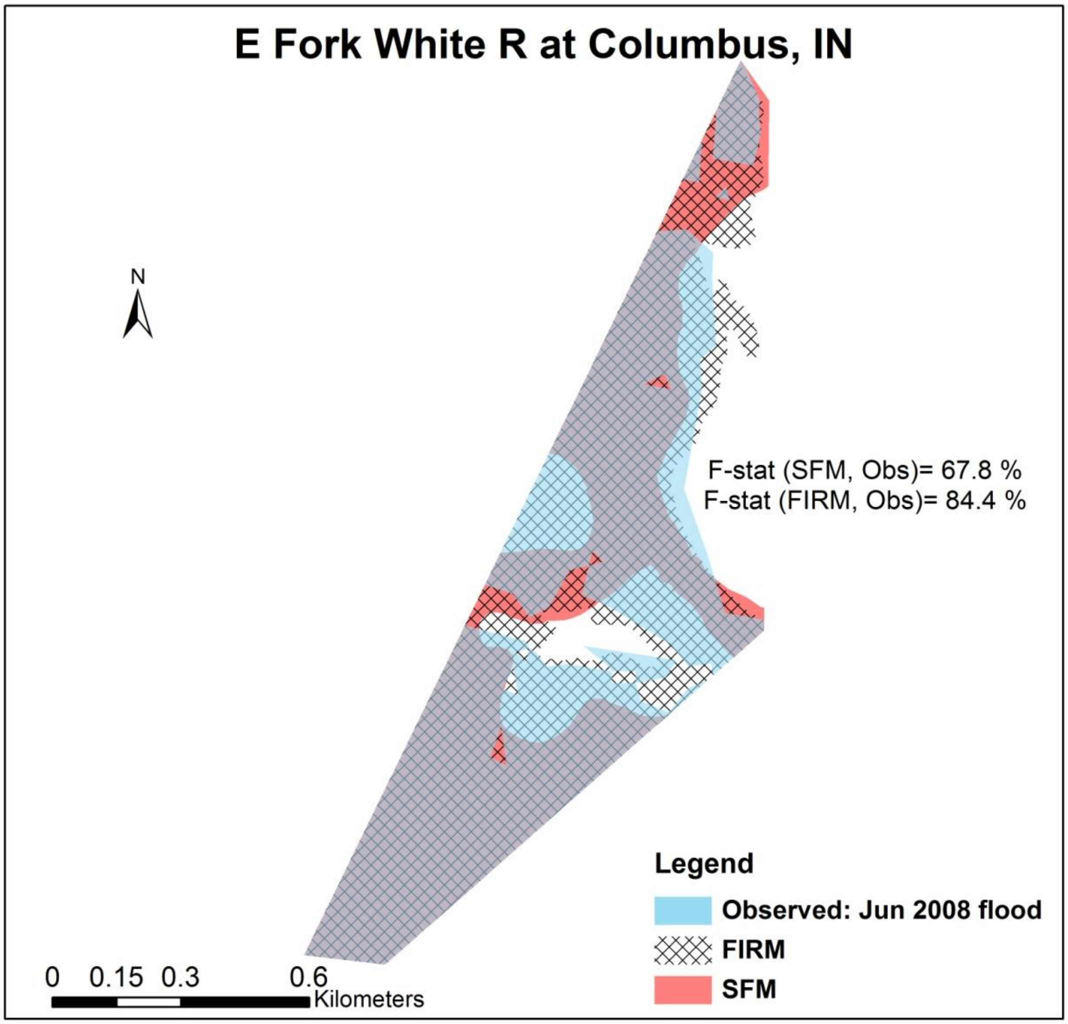

E Fork White R at Columbus, IN
N
F-stat (SFM, Obs)= 67.8 %
F-stat (FIRM, Obs)= 84.4 %
Legend
Observed: Jun 2008 flood
FIRM
SFM
0 0.15 0.3 0.6
Kilometers

Figure C.4

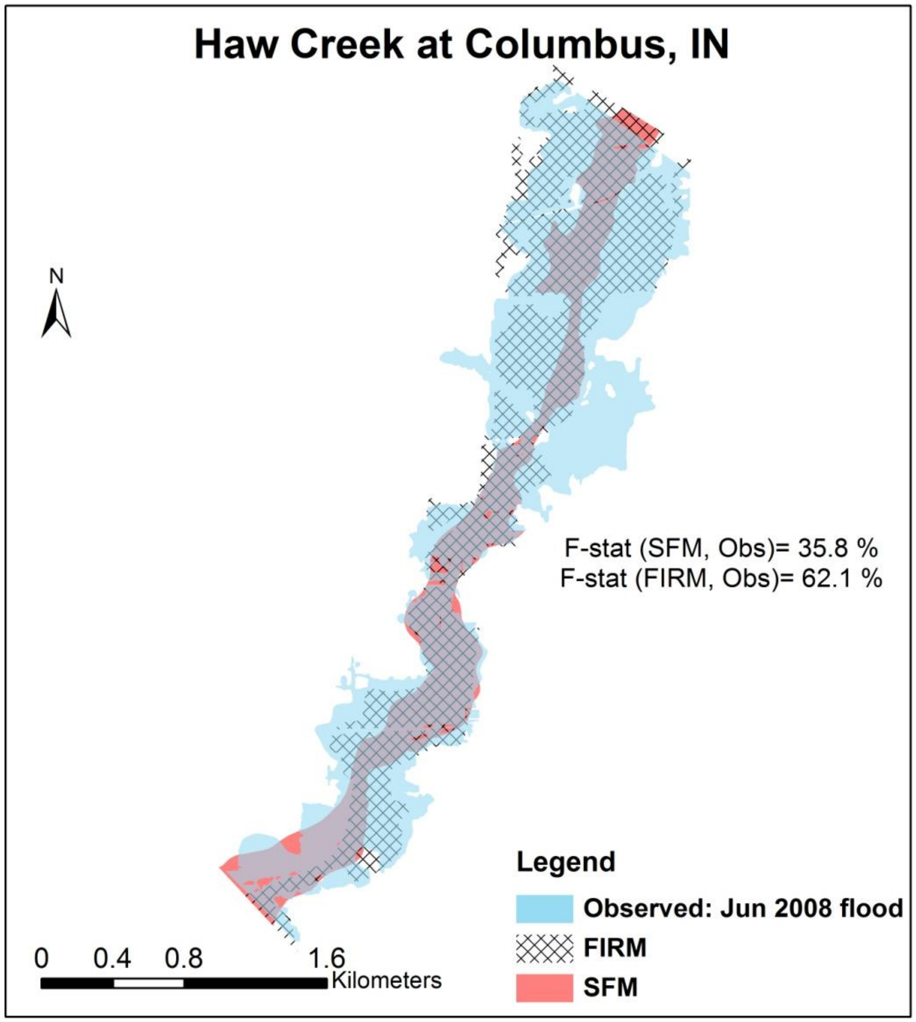

Haw Creek at Columbus, IN
N
F-stat (SFM, Obs)= 35.8 %
F-stat (FIRM, Obs)= 62.1 %
Legend
Observed: Jun 2008 flood
FIRM
SFM
0 0.4 0.8 1.6
Kilometers

Figure C.5

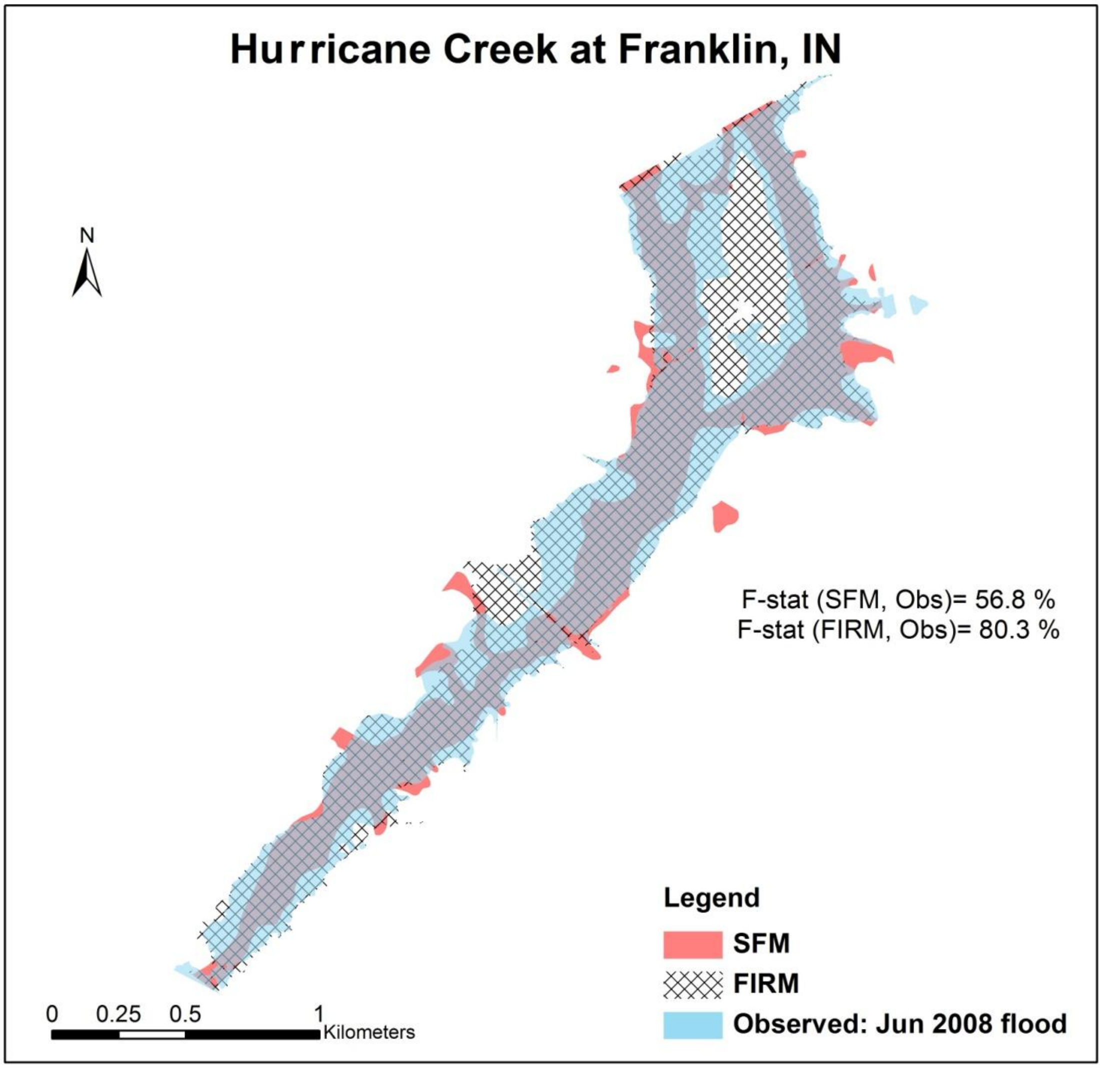

Hurricane Creek at Franklin, IN
N
F-stat (SFM, Obs)= 56.8 %
F-stat (FIRM, Obs)= 80.3 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.25 0.5 1
Kilometers

Figure C.6

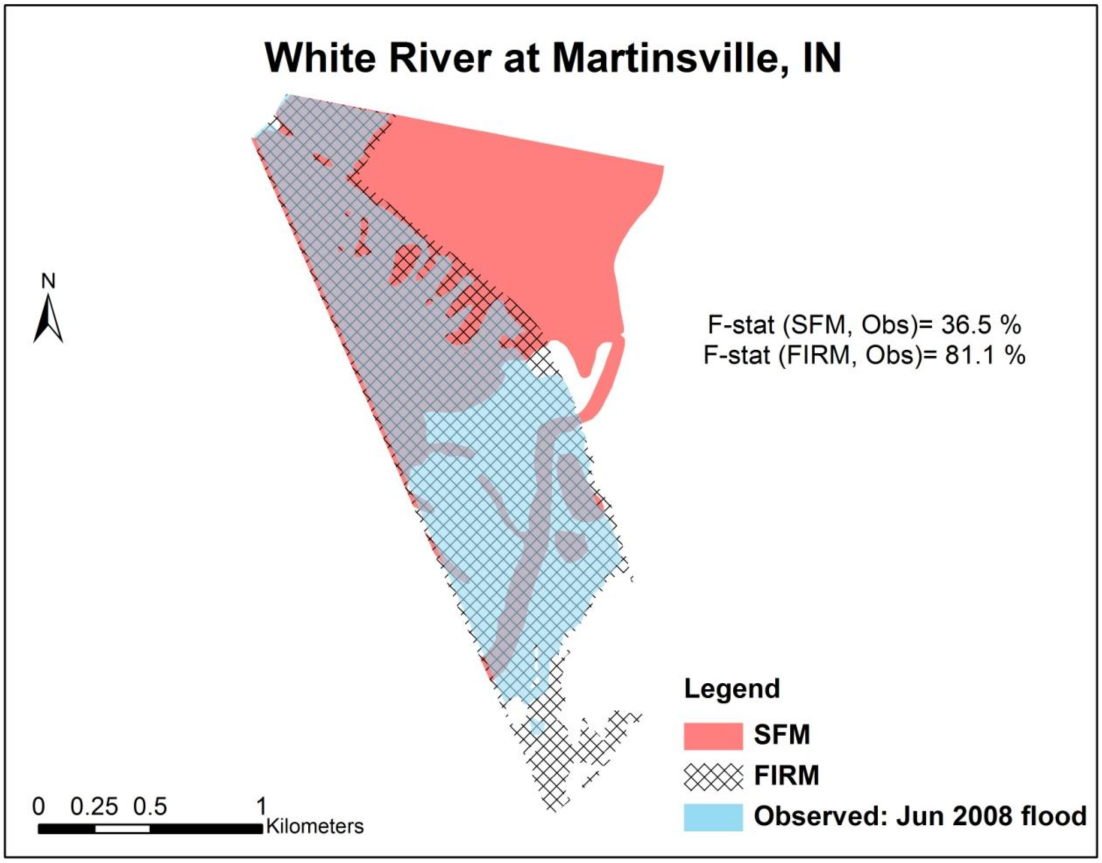

White River at Martinsville, IN
N
F-stat (SFM, Obs)= 36.5 %
F-stat (FIRM, Obs)= 81.1 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.25 0.5 1
Kilometers

Figure C.7

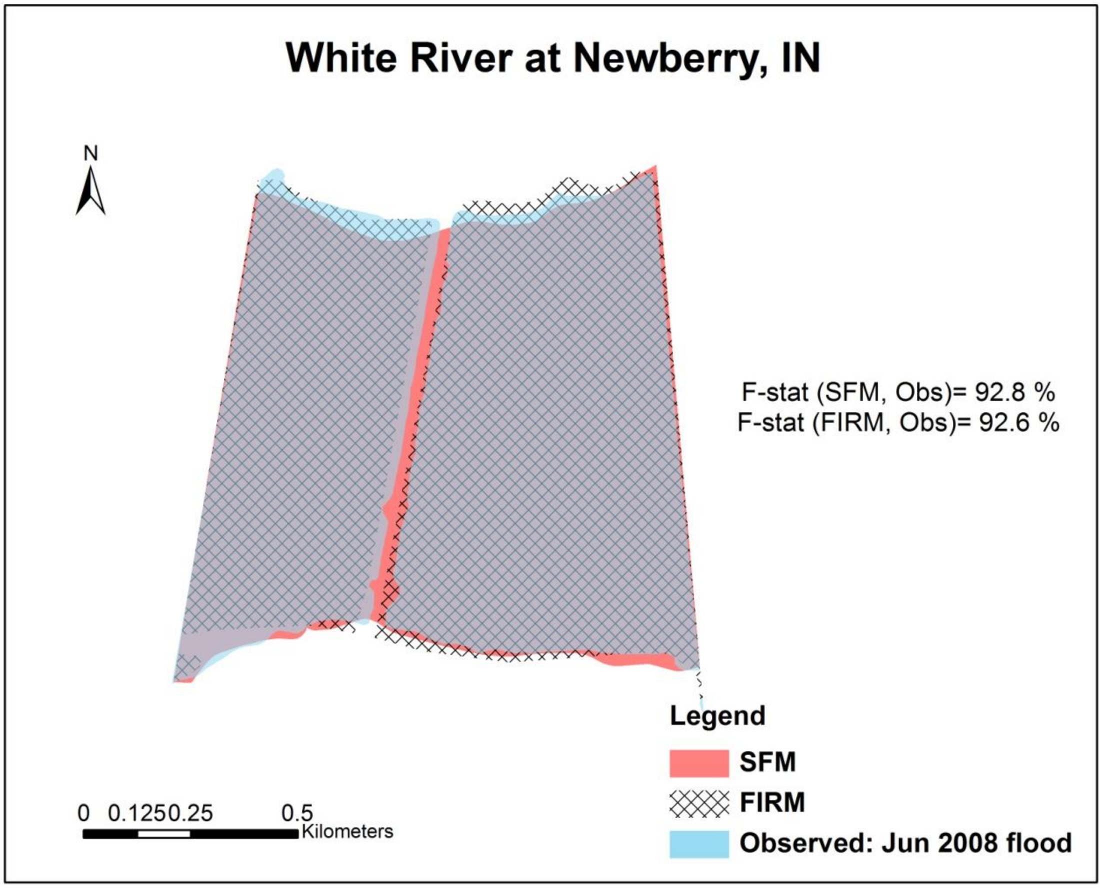

White River at Newberry, IN
N
F-stat (SFM, Obs)= 92.8 %
F-stat (FIRM, Obs)= 92.6 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.1250.25 0.5
Kilometers

Figure C.8

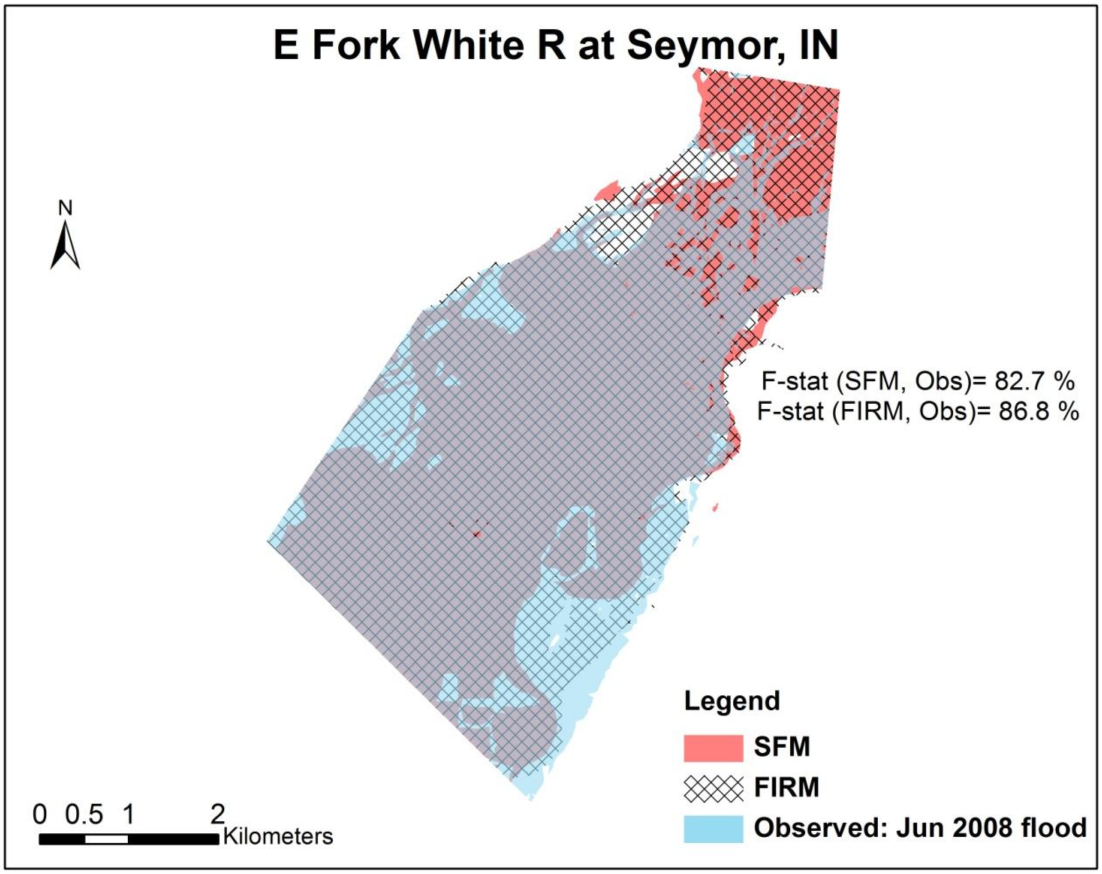

E Fork White R at Seymor, IN
N
F-stat (SFM, Obs)= 82.7 %
F-stat (FIRM, Obs)= 86.8 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.5 1 2
Kilometers

Figure C.9

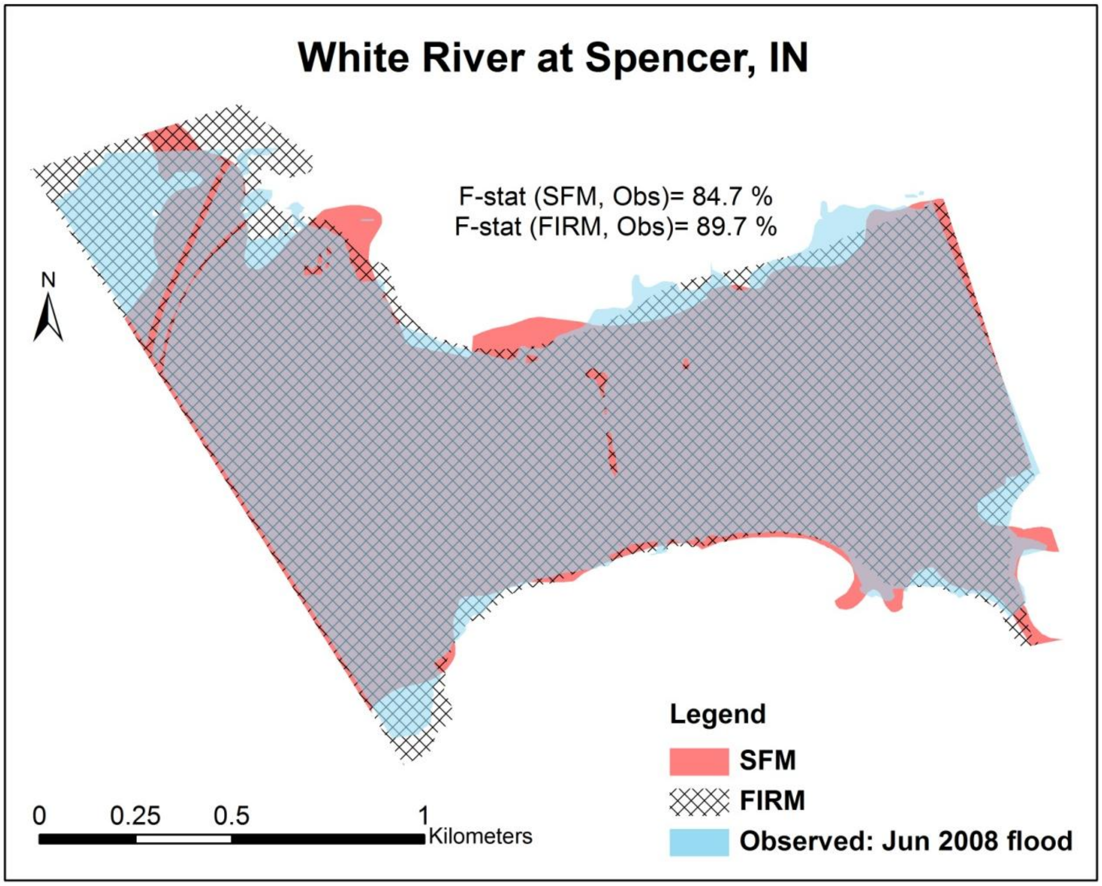

White River at Spencer, IN
F-stat (SFM, Obs)= 84.7 %
F-stat (FIRM, Obs)= 89.7 %
N
Legend
SFM
FIRM
Observed: Jun 2008 flood
0
0.25
0.5
1
Kilometers

Figure C.10

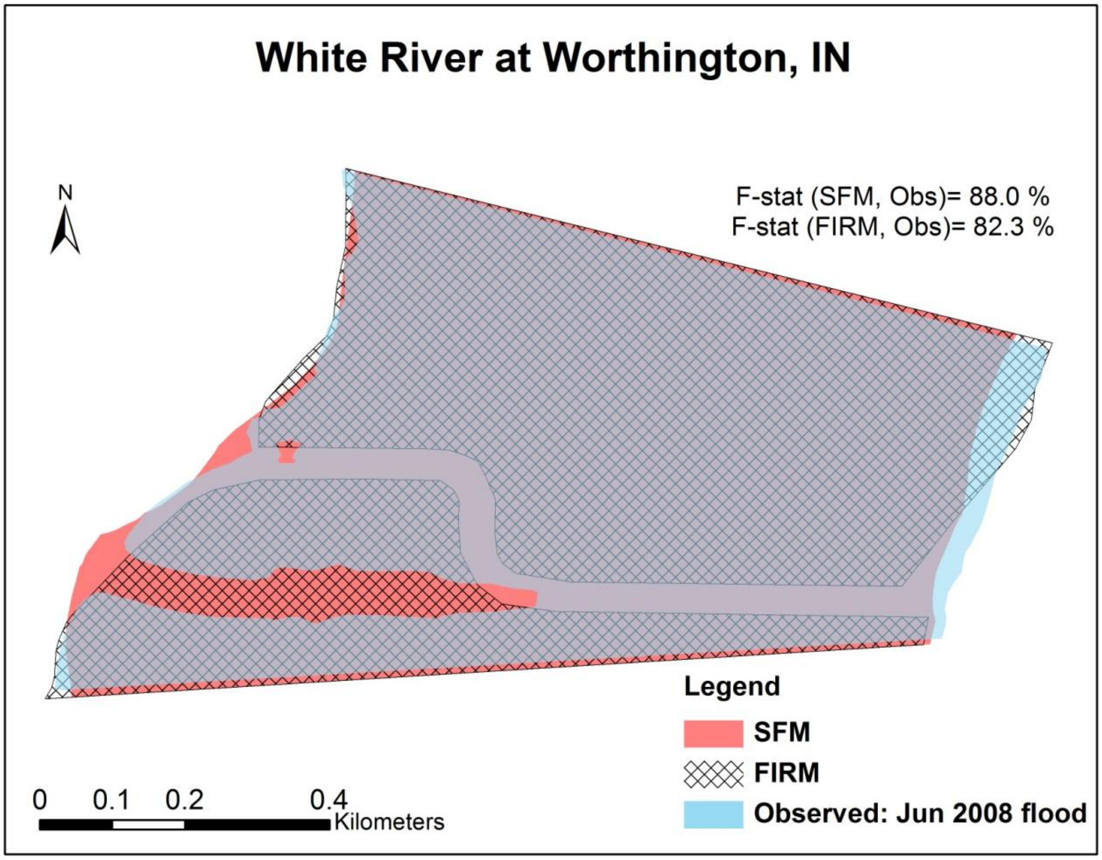

White River at Worthington, IN
N
F-stat (SFM, Obs)= 88.0 %
F-stat (FIRM, Obs)= 82.3 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0
0.1
0.2
0.4
Kilometers

Figure C.11

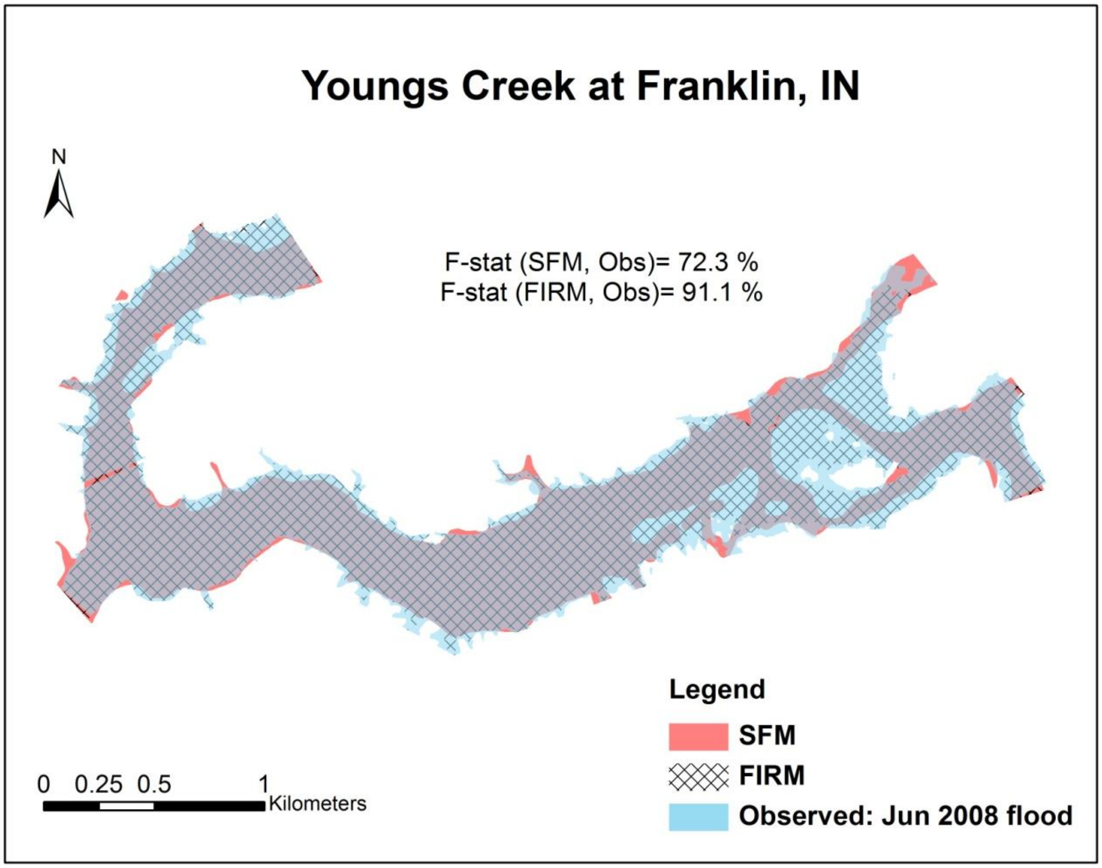

Youngs Creek at Franklin, IN
N
F-stat (SFM, Obs)= 72.3 %
F-stat (FIRM, Obs)= 91.1 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.25 0.5 1
Kilometers

Figure C.12

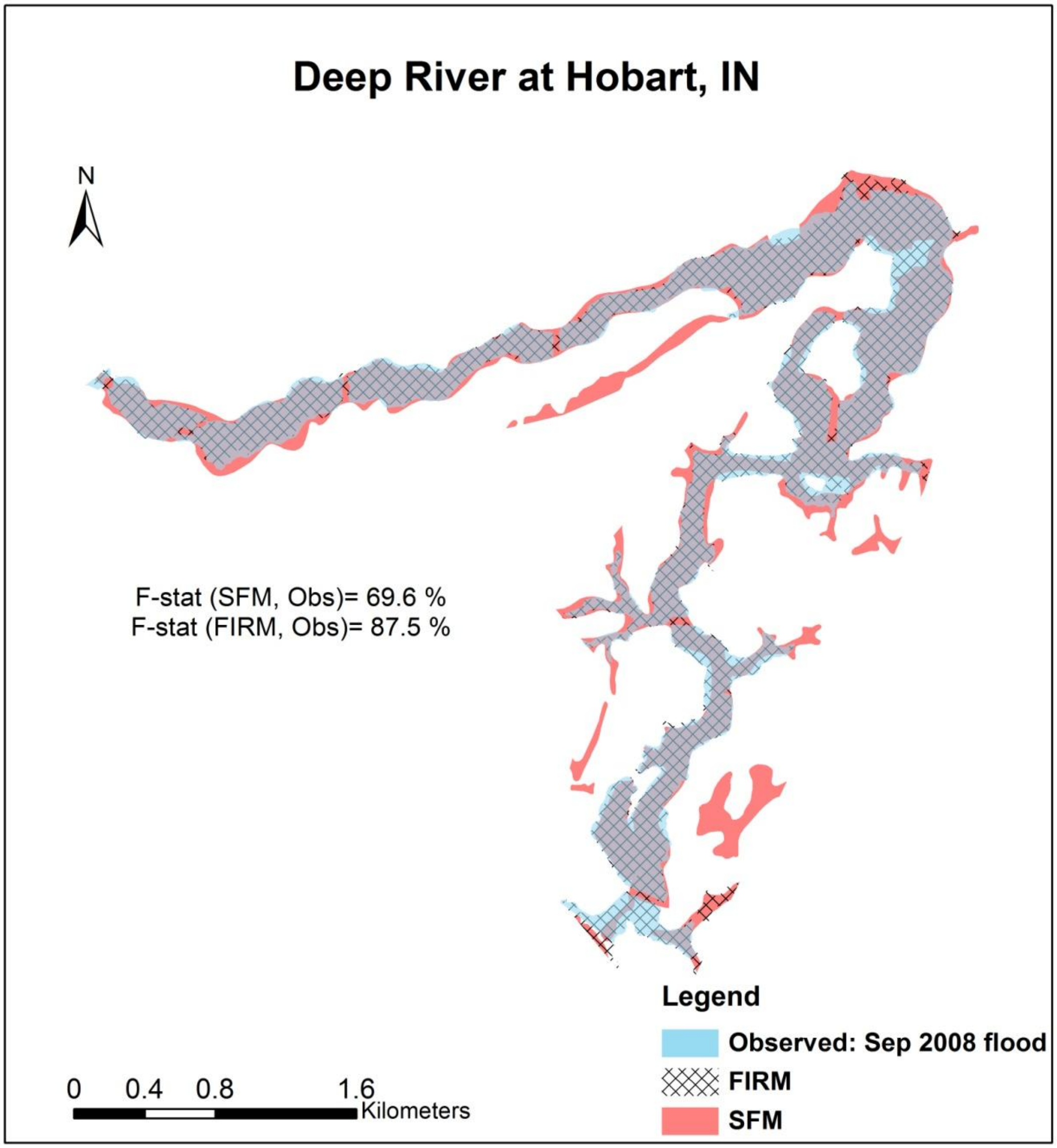

Deep River at Hobart, IN
N
F-stat (SFM, Obs)= 69.6 %
F-stat (FIRM, Obs)= 87.5 %
Legend
Observed: Sep 2008 flood
FIRM
SFM
0 0.4 0.8 1.6
Kilometers

Figure C.13

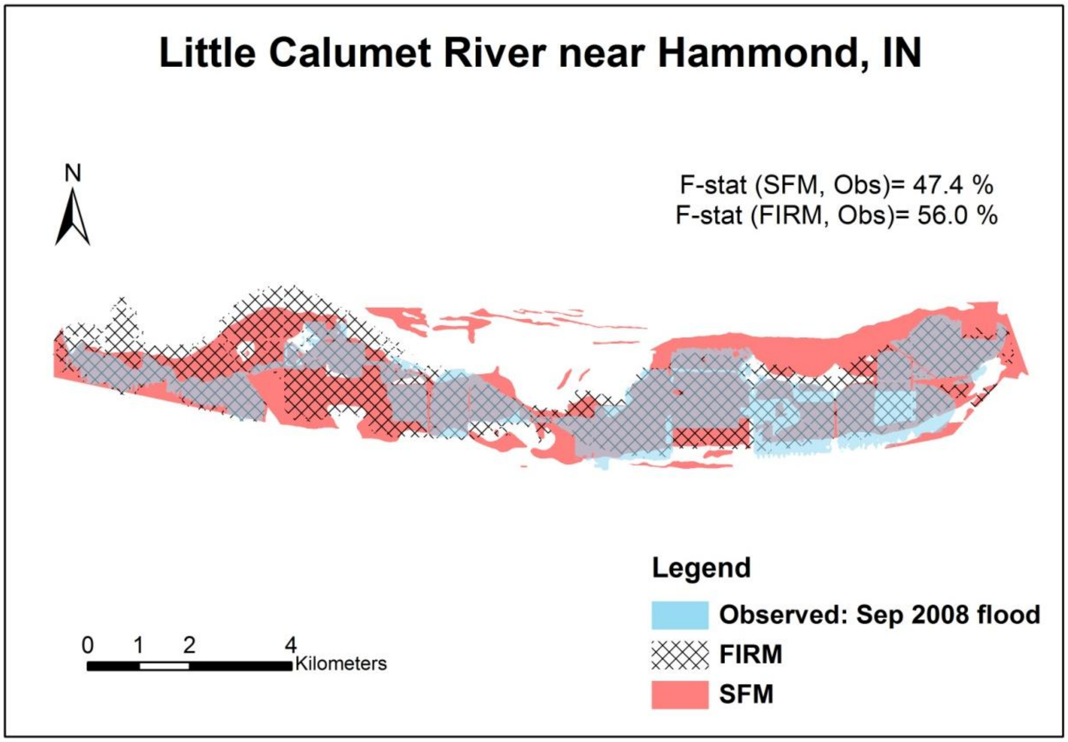

Little Calumet River near Hammond, IN
N
F-stat (SFM, Obs)= 47.4 %
F-stat (FIRM, Obs)= 56.0 %
Legend
Observed: Sep 2008 flood
FIRM
SFM
0 1 2 4
Kilometers

Figure C.14

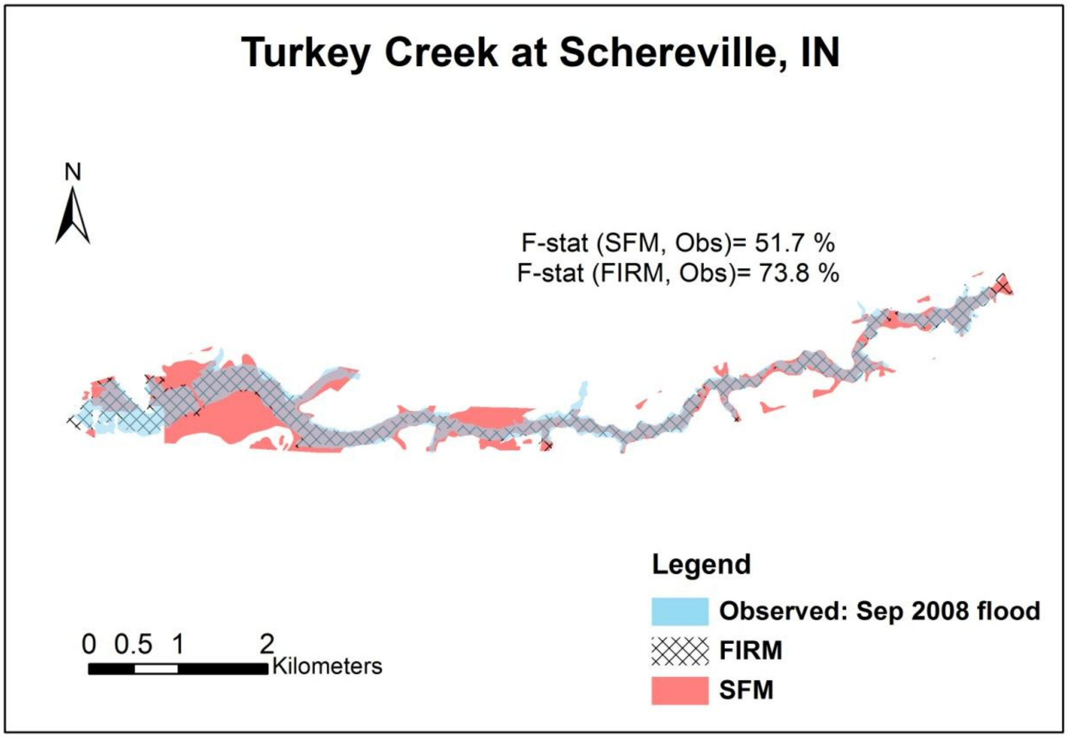

Turkey Creek at Schereville, IN
N
F-stat (SFM, Obs)= 51.7 %
F-stat (FIRM, Obs)= 73.8 %
Legend
Observed: Sep 2008 flood
FIRM
SFM
0 0.5 1 2
Kilometers

Figure C.15

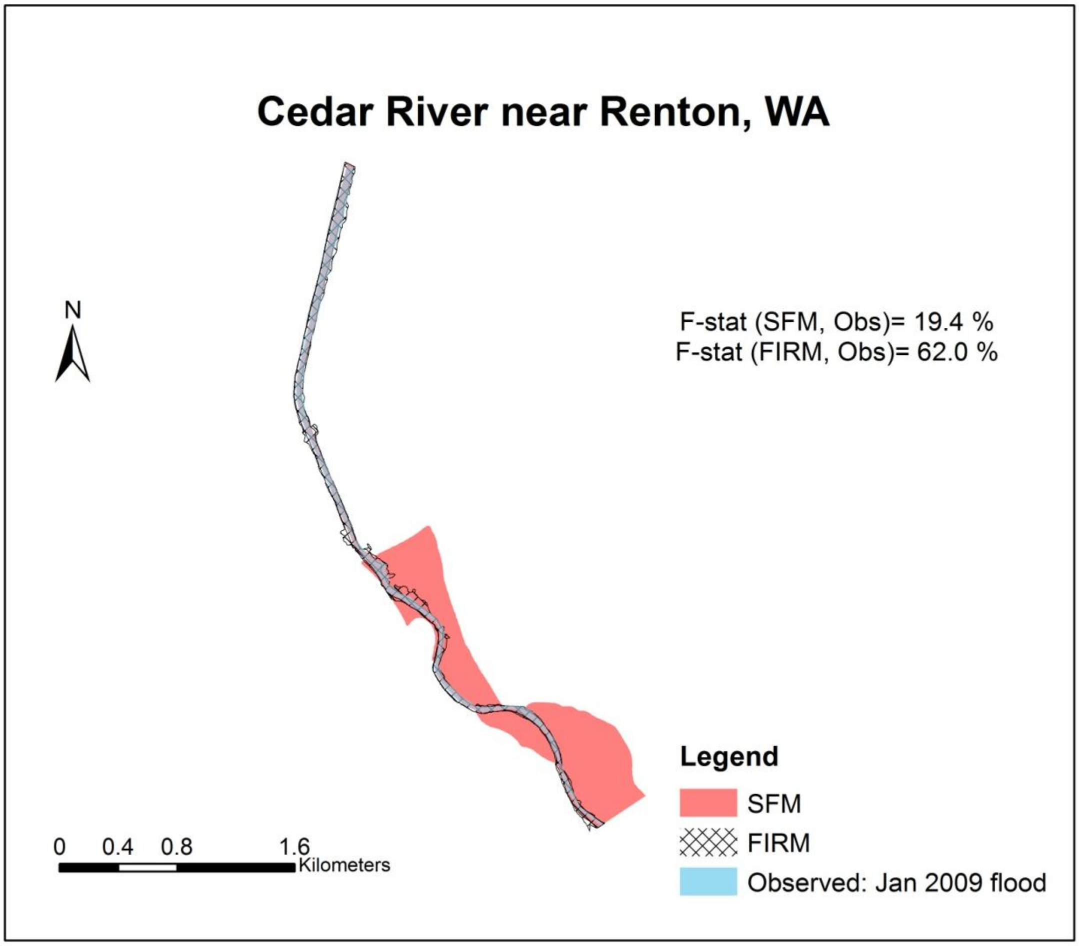

Cedar River near Renton, WA
N
F-stat (SFM, Obs)= 19.4 %
F-stat (FIRM, Obs)= 62.0 %
0 0.4 0.8 1.6
Kilometers
Legend
SFM
FIRM
Observed: Jan 2009 flood

Figure C.16

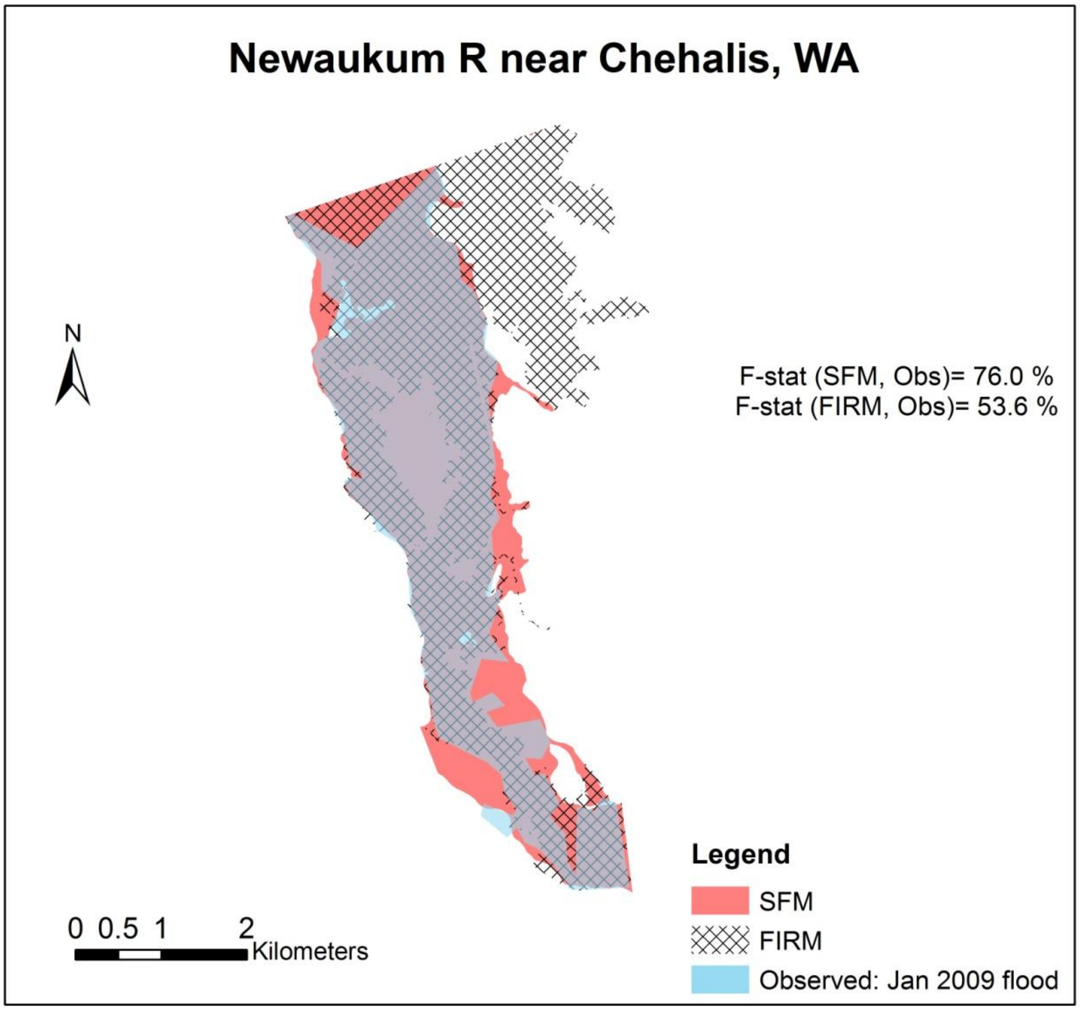

Newaukum R near Chehalis, WA
N
F-stat (SFM, Obs)= 76.0 %
F-stat (FIRM, Obs)= 53.6 %
Legend
SFM
FIRM
Observed: Jan 2009 flood
0 0.5 1 2
Kilometers

Figure C.17

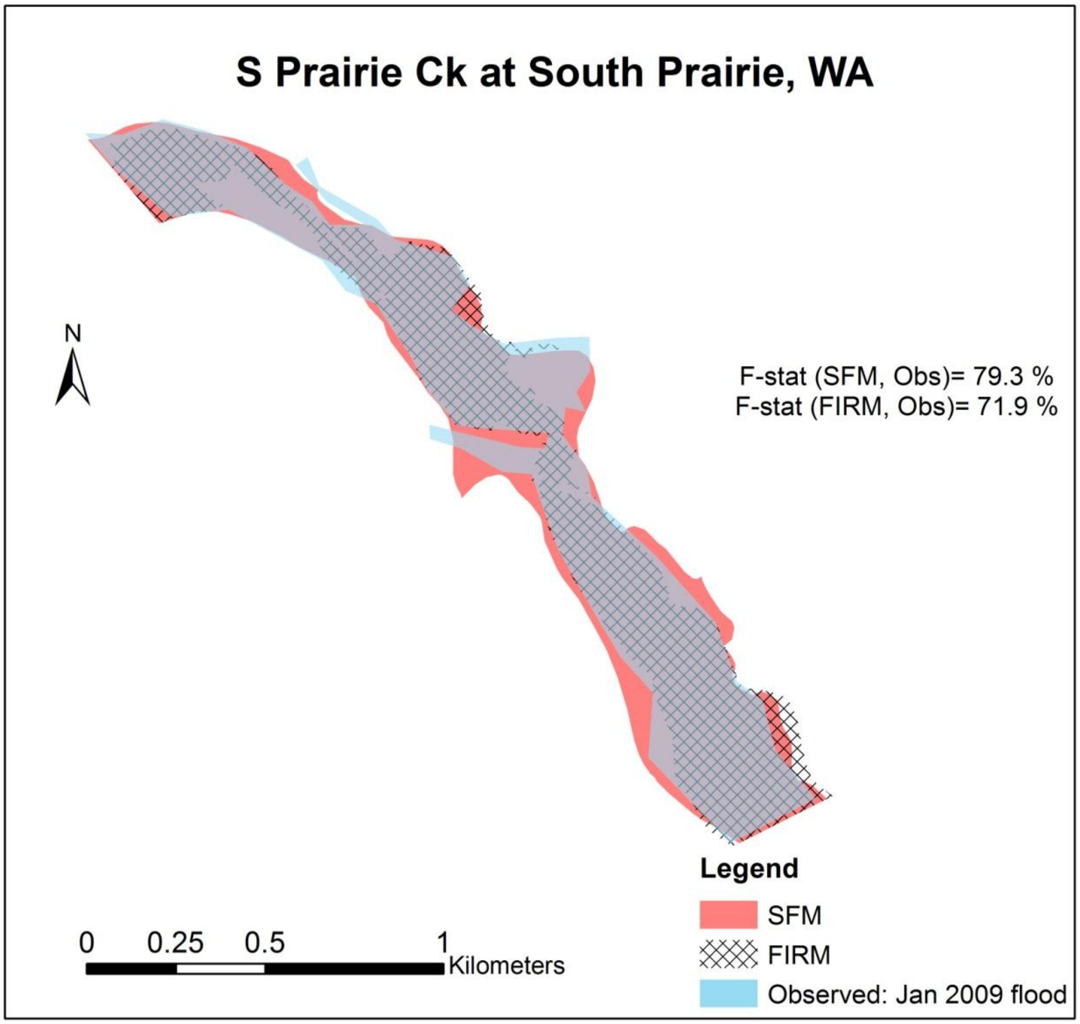

S Prairie Ck at South Prairie, WA
N
F-stat (SFM, Obs)= 79.3 %
F-stat (FIRM, Obs)= 71.9 %
Legend
SFM
FIRM
Observed: Jan 2009 flood
0 0.25 0.5 1
Kilometers

Figure C.18

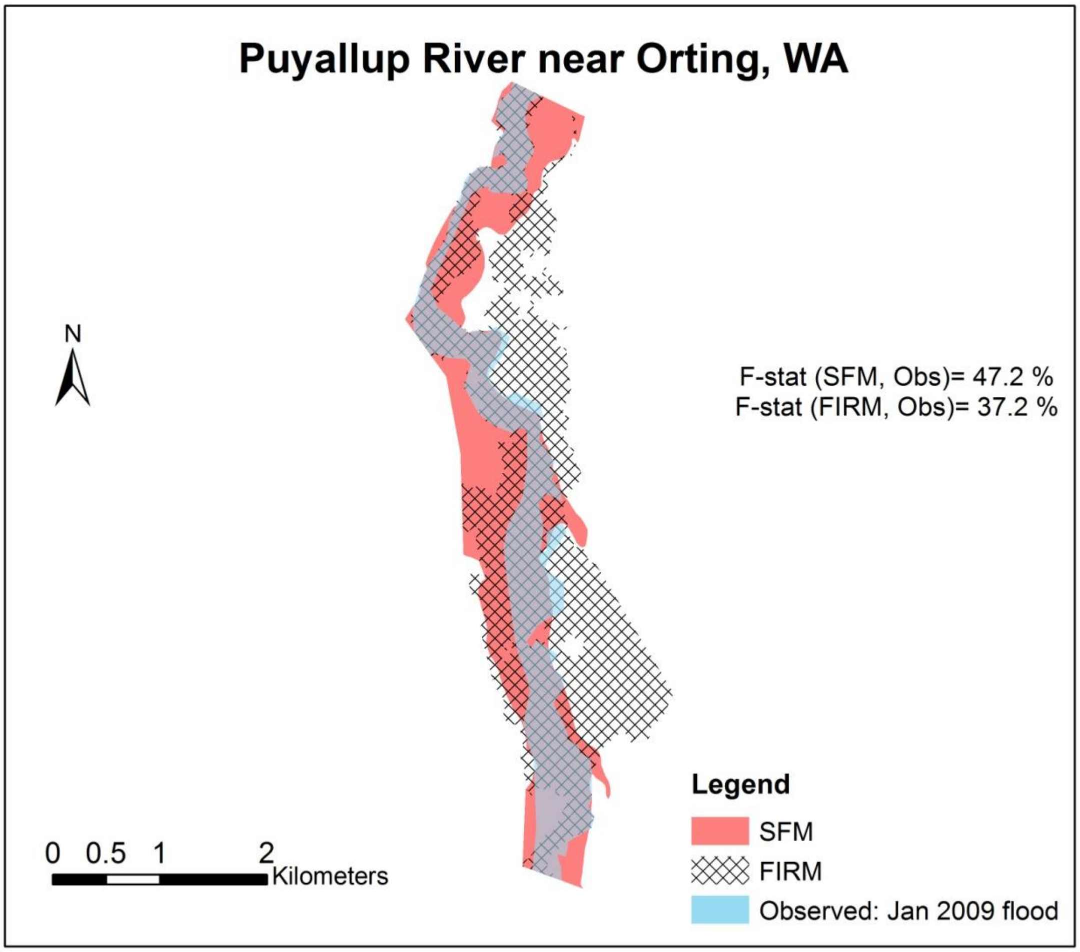

Puyallup River near Orting, WA
N
F-stat (SFM, Obs)= 47.2 %
F-stat (FIRM, Obs)= 37.2 %
0 0.5 1 2 Kilometers
Legend
SFM
FIRM
Observed: Jan 2009 flood

Figure C.19

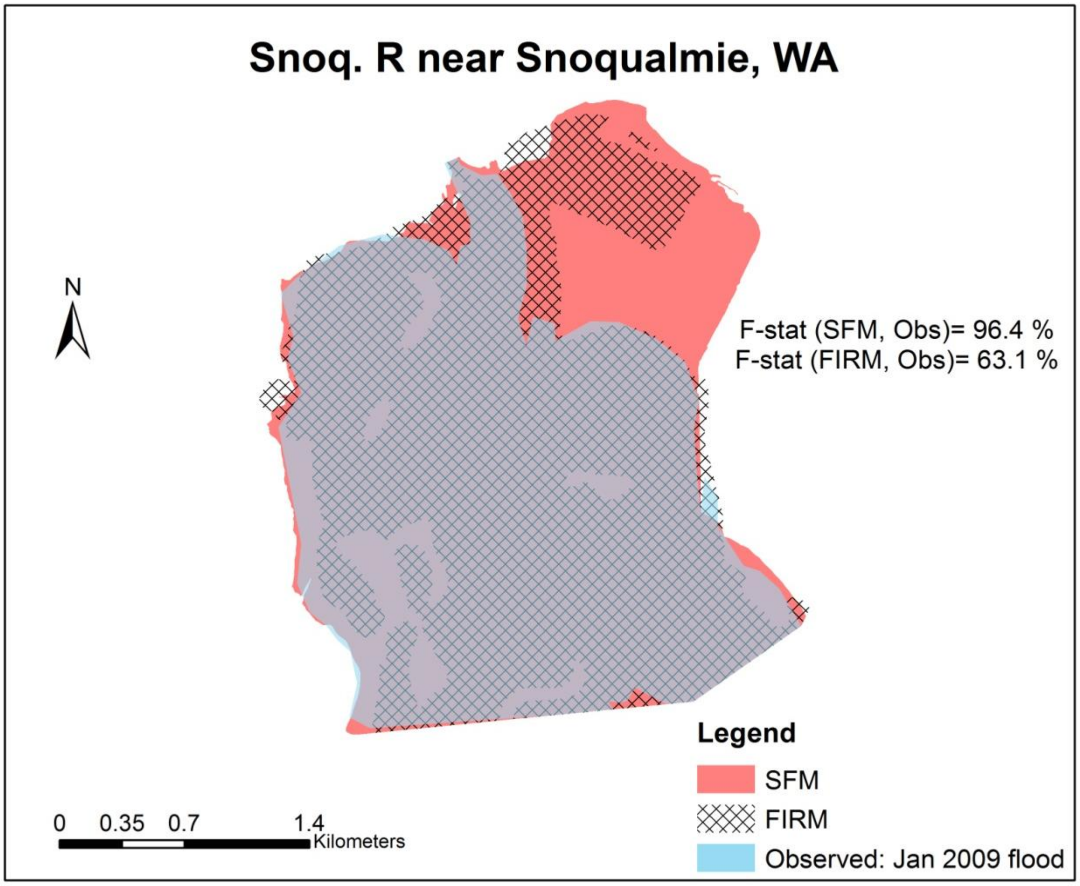

Snoq. R near Snoqualmie, WA
N
F-stat (SFM, Obs)= 96.4 %
F-stat (FIRM, Obs)= 63.1 %
Legend
SFM
FIRM
Observed: Jan 2009 flood
0 0.35 0.7 1.4
Kilometers

Figure C.20

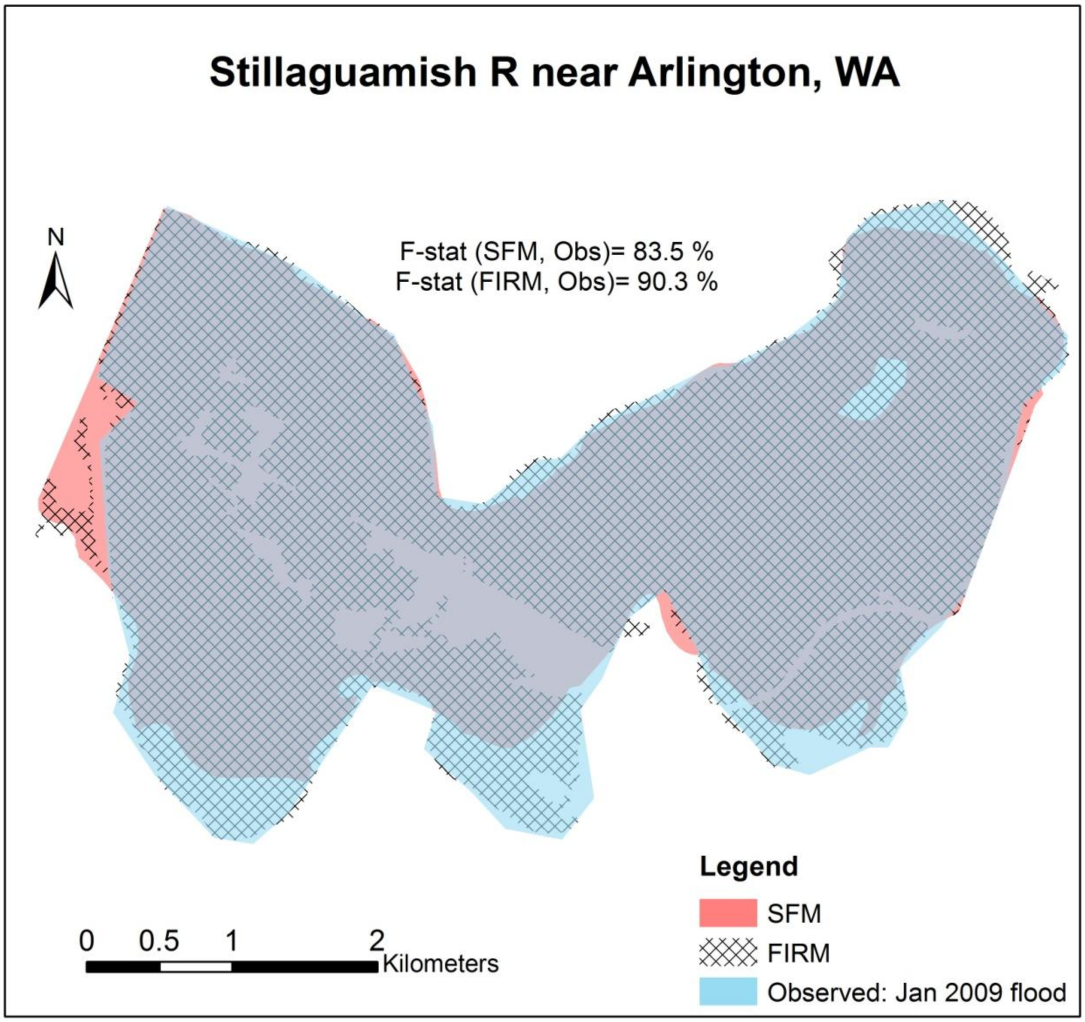

Stillaguamish R near Arlington, WA
N
F-stat (SFM, Obs)= 83.5 %
F-stat (FIRM, Obs)= 90.3 %
0 0.5 1 2
Kilometers
Legend
SFM
FIRM
Observed: Jan 2009 flood

Figure C.21

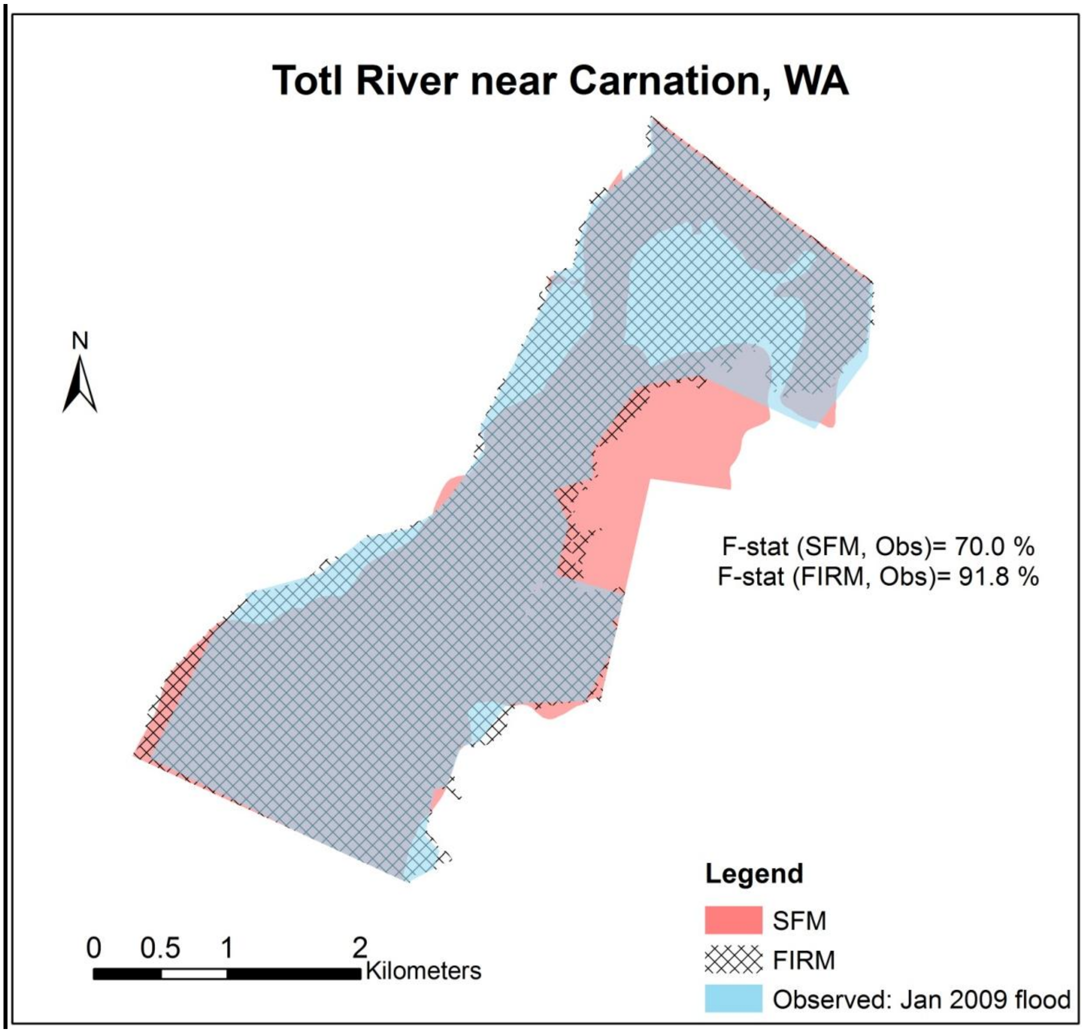

Totl River near Carnation, WA
N
F-stat (SFM, Obs)= 70.0 %
F-stat (FIRM, Obs)= 91.8 %
0 0.5 1 2
Kilometers
Legend
SFM
FIRM
Observed: Jan 2009 flood

Figure C.22

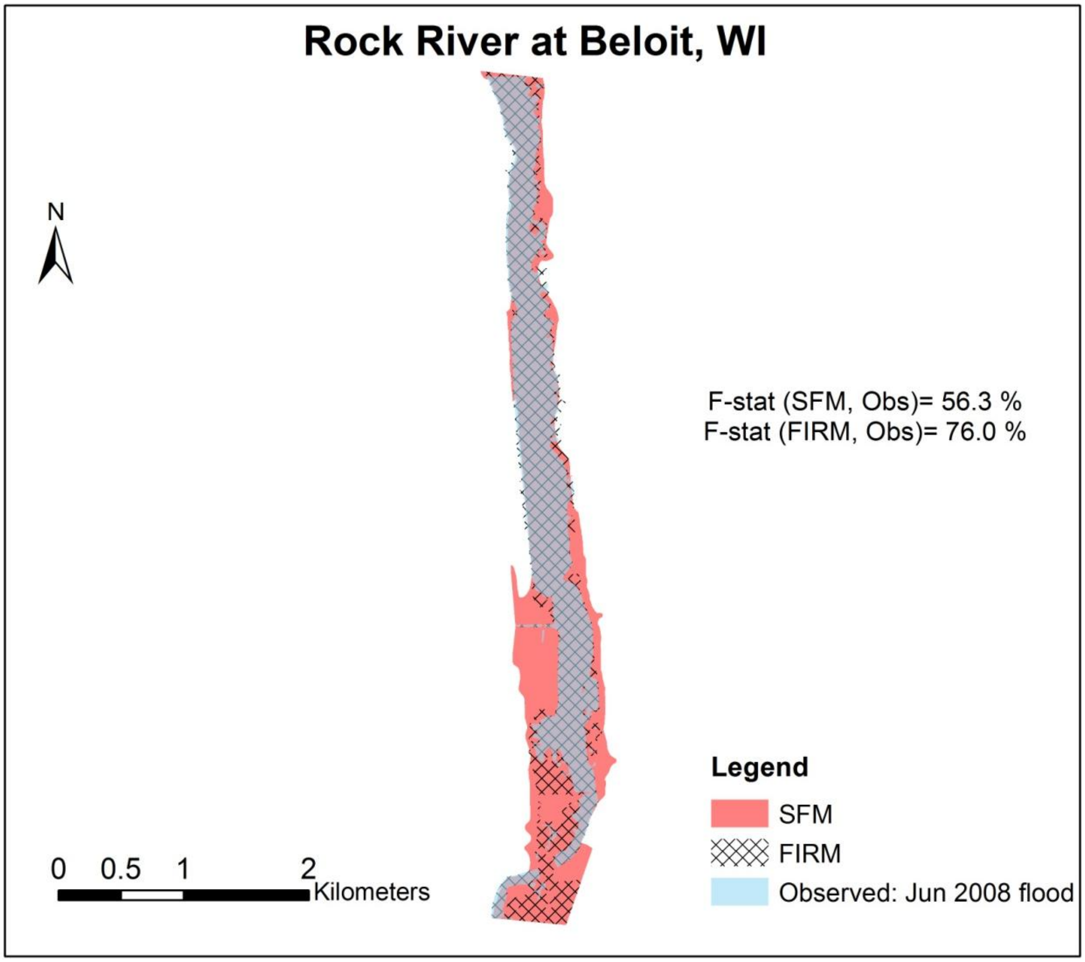

Rock River at Beloit, WI
N
F-stat (SFM, Obs)= 56.3 %
F-stat (FIRM, Obs)= 76.0 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.5 1 2
Kilometers

Figure C.23

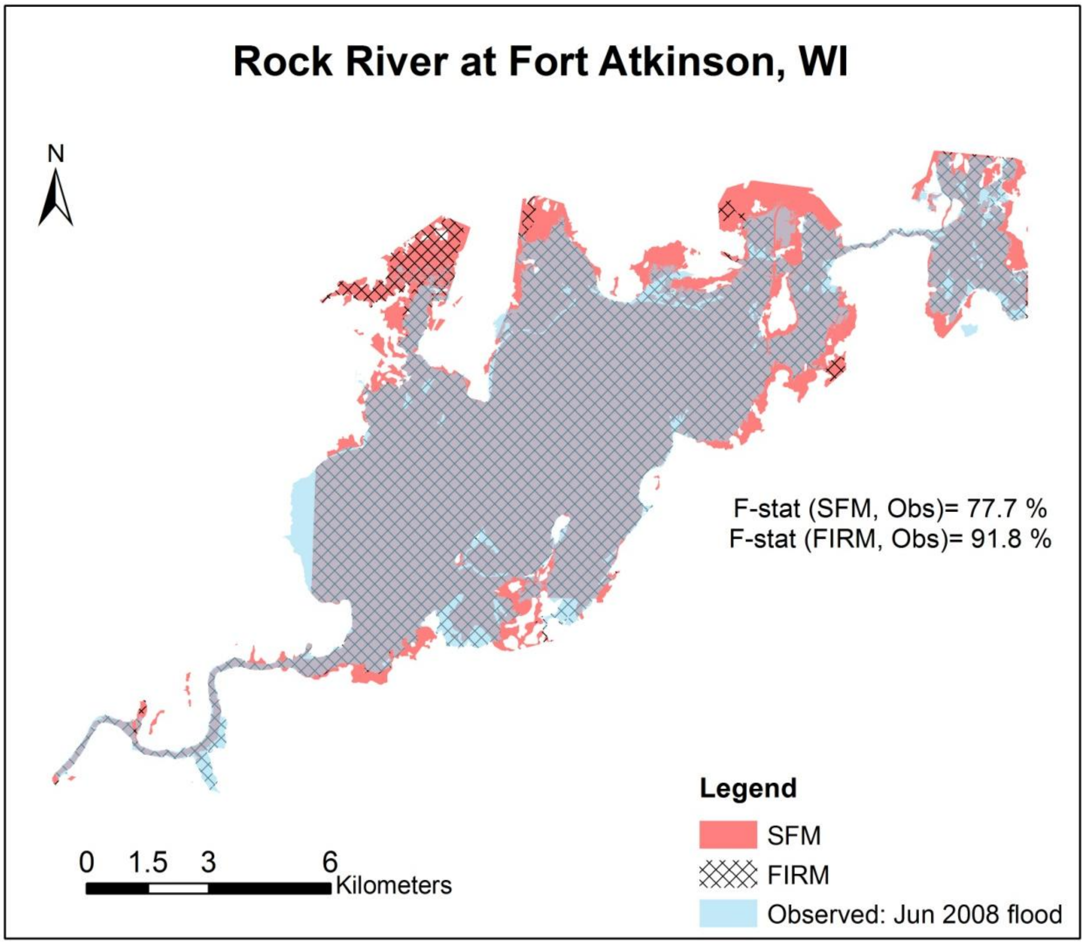

Rock River at Fort Atkinson, WI
N
F-stat (SFM, Obs)= 77.7 %
F-stat (FIRM, Obs)= 91.8 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 1.5 3 6
Kilometers

Figure C.24

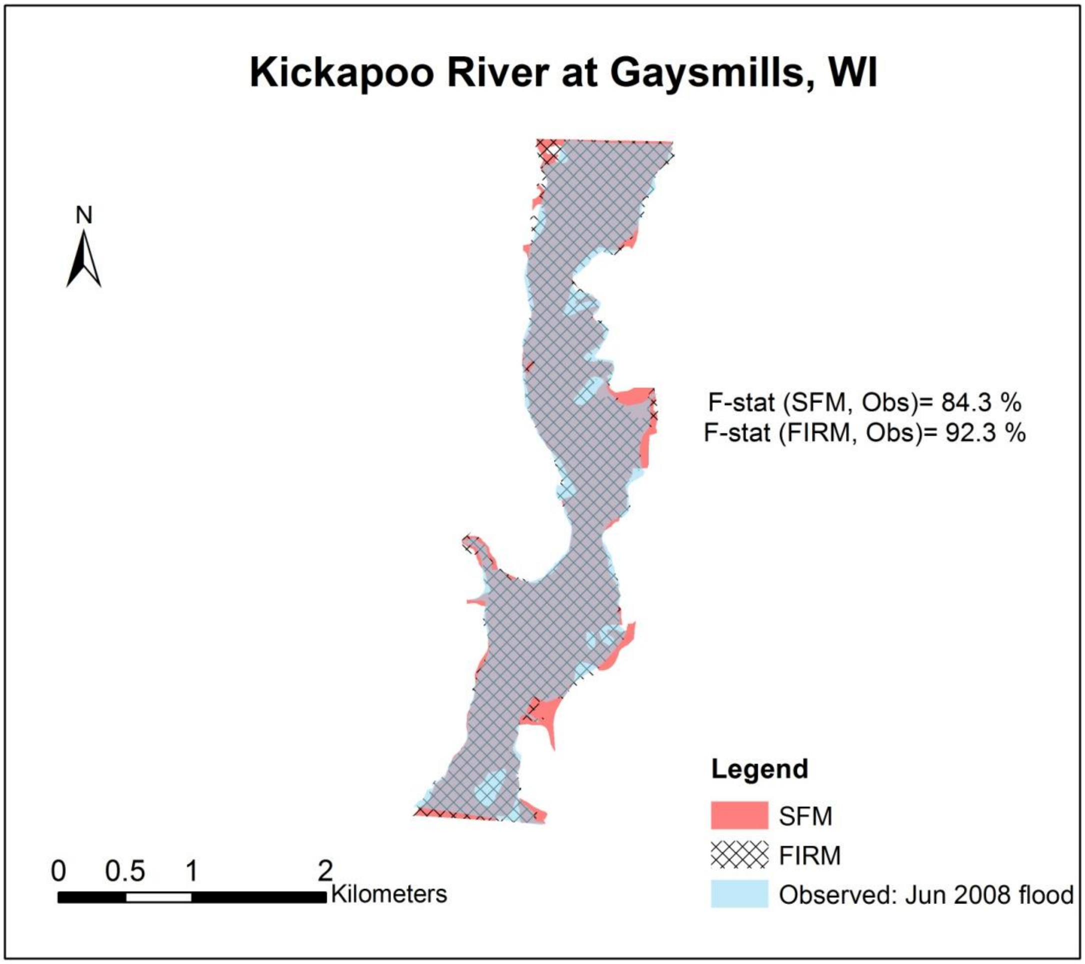

Kickapoo River at Gaysmills, WI
N
F-stat (SFM, Obs)= 84.3 %
F-stat (FIRM, Obs)= 92.3 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.5 1 2
Kilometers

Figure C.25

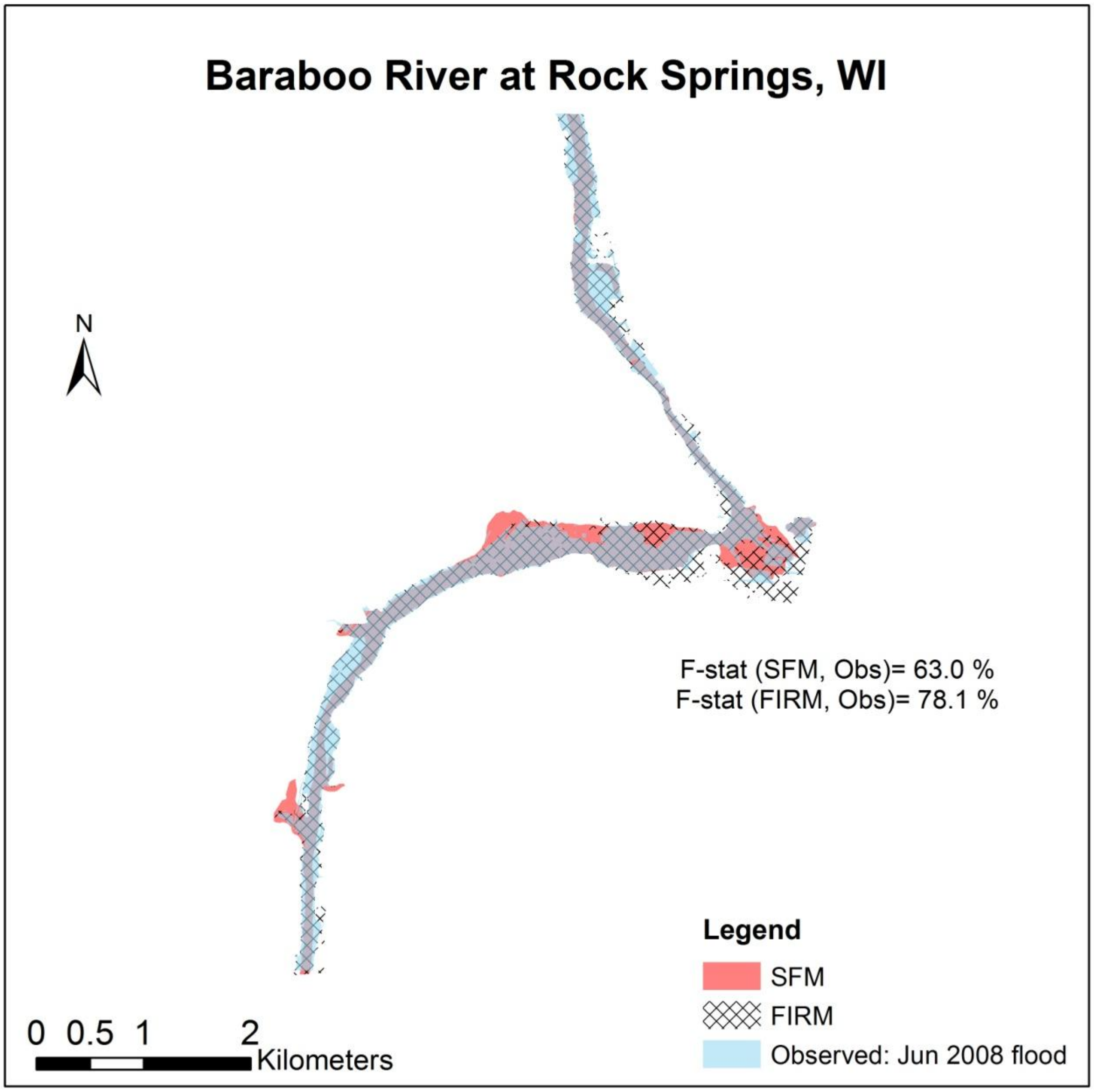

Baraboo River at Rock Springs, WI
N
F-stat (SFM, Obs)= 63.0 %
F-stat (FIRM, Obs)= 78.1 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.5 1 2
Kilometers

Figure C.26

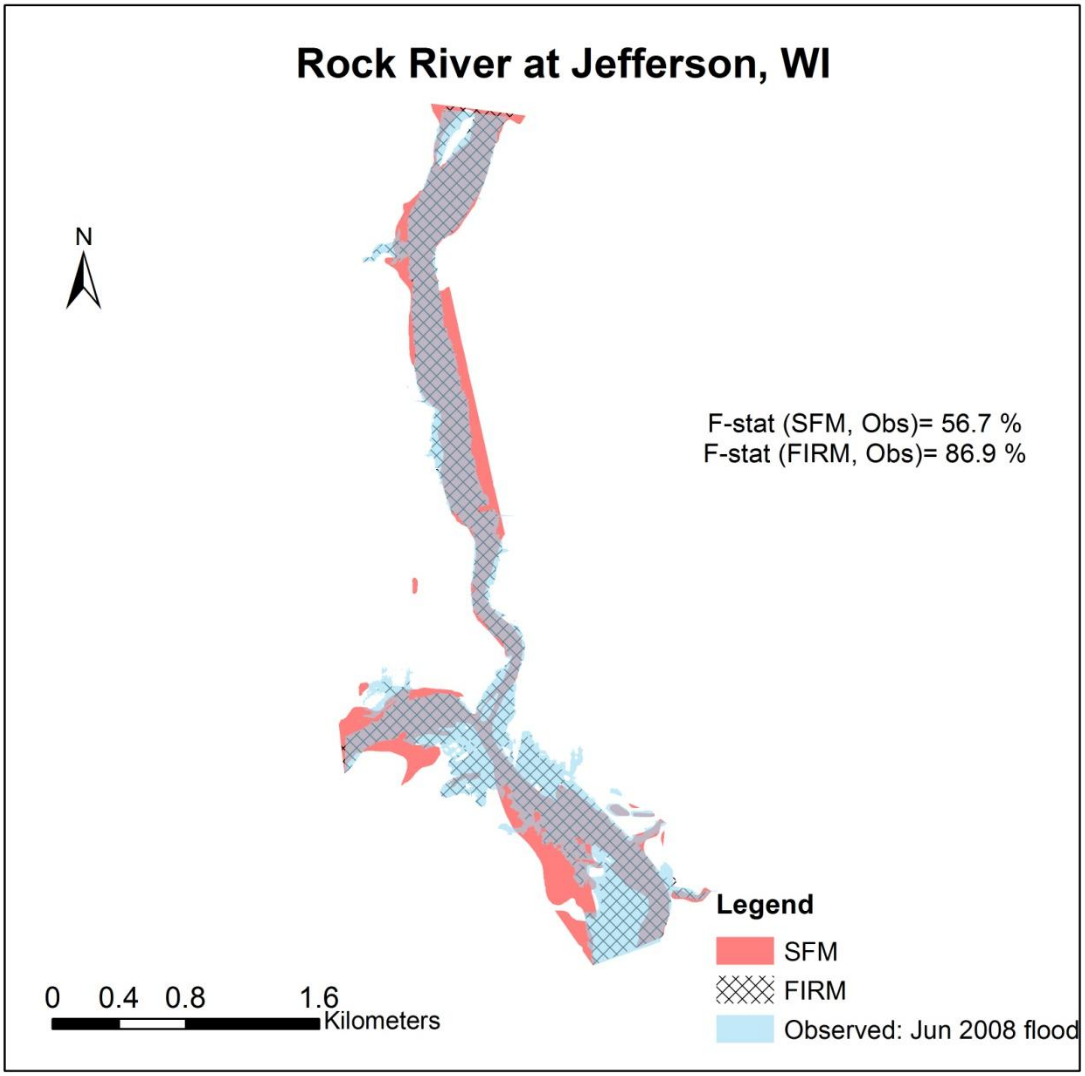

Rock River at Jefferson, WI
N
F-stat (SFM, Obs)= 56.7 %
F-stat (FIRM, Obs)= 86.9 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.4 0.8 1.6
Kilometers

Figure C.27

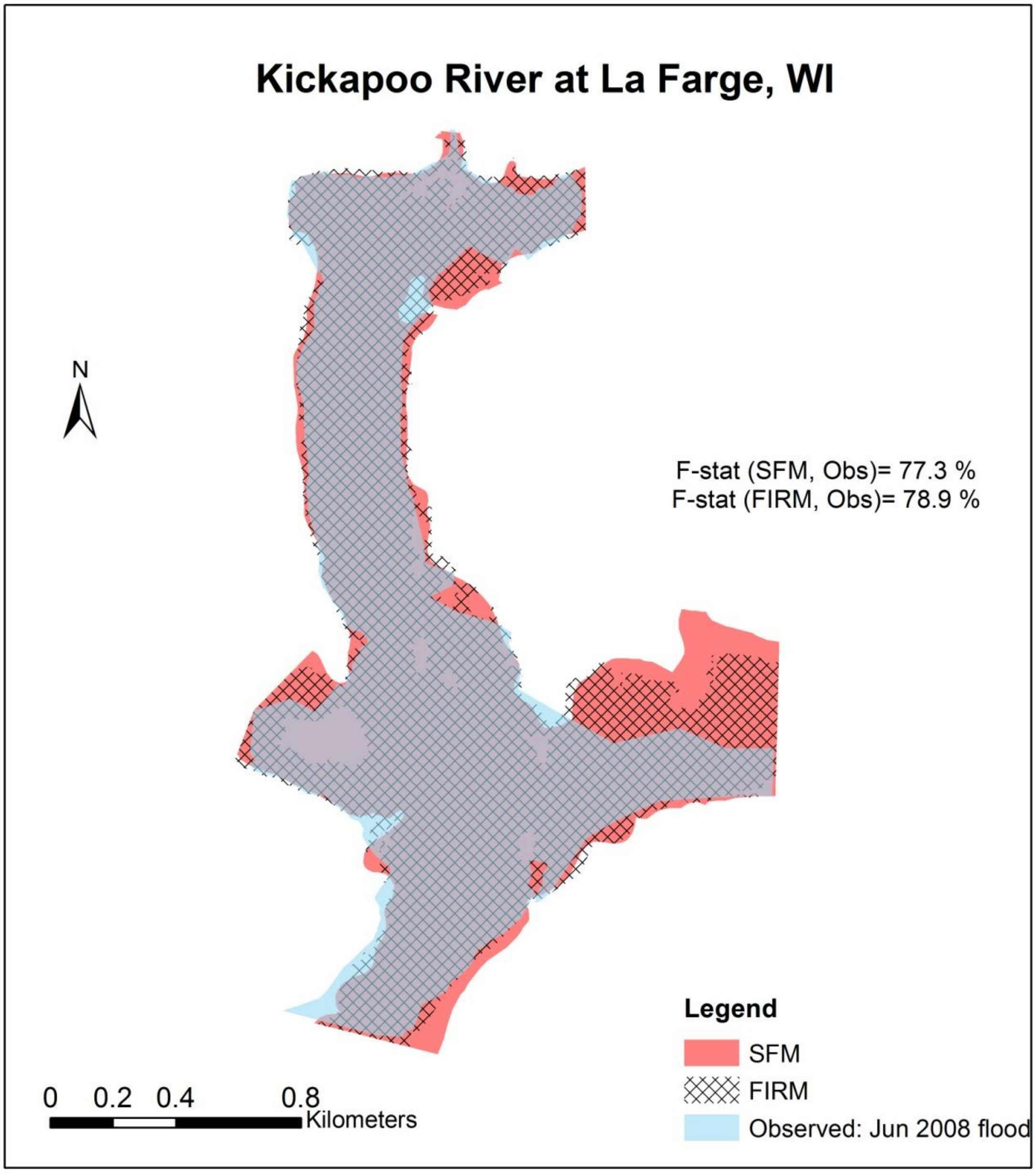

Kickapoo River at La Farge, WI
N
F-stat (SFM, Obs)= 77.3 %
F-stat (FIRM, Obs)= 78.9 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.2 0.4 0.8
Kilometers

Figure C.28

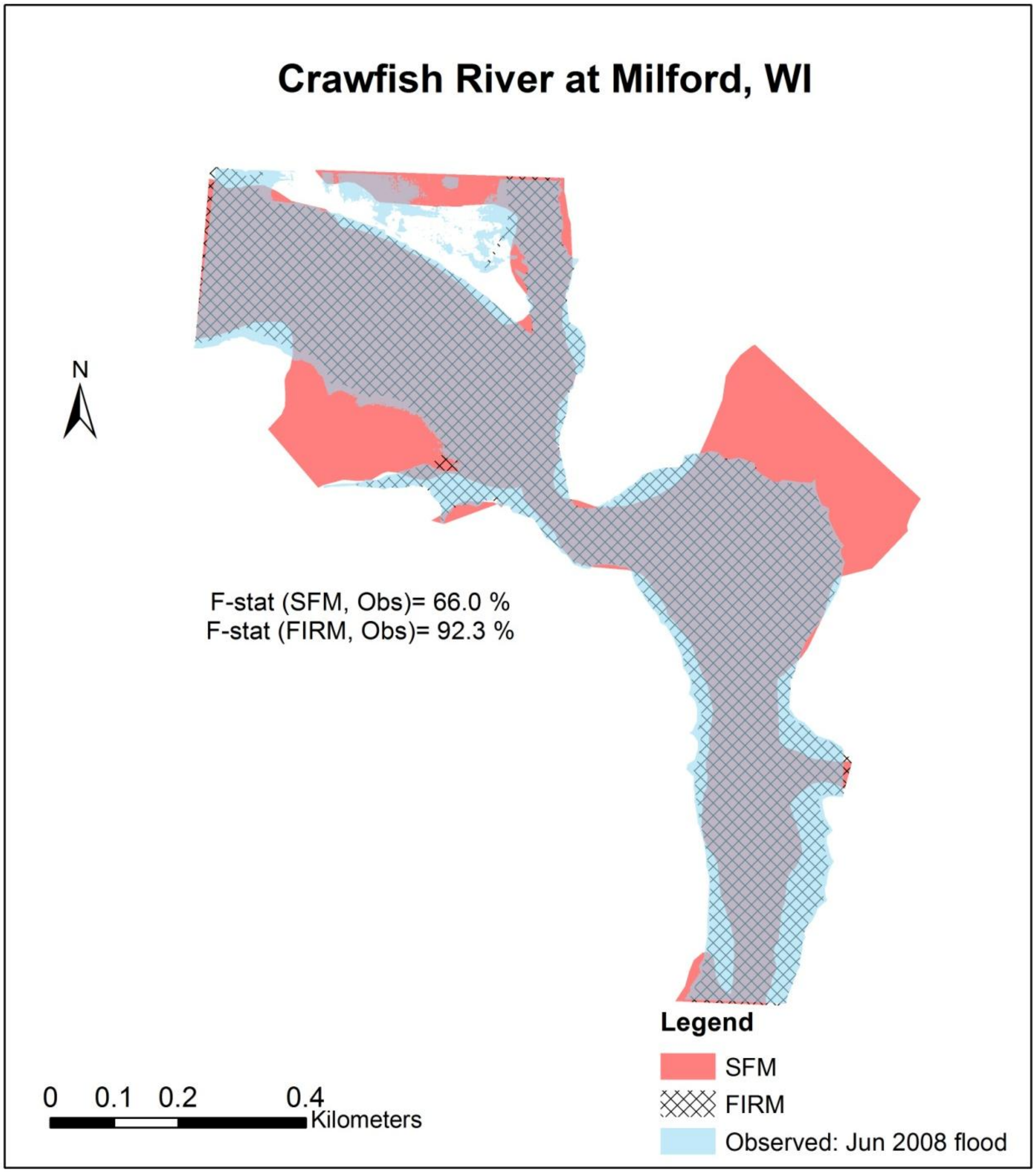

Crawfish River at Milford, WI
N
F-stat (SFM, Obs)= 66.0 %
F-stat (FIRM, Obs)= 92.3 %
0 0.1 0.2 0.4
Kilometers
Legend
SFM
FIRM
Observed: Jun 2008 flood

Figure C.29

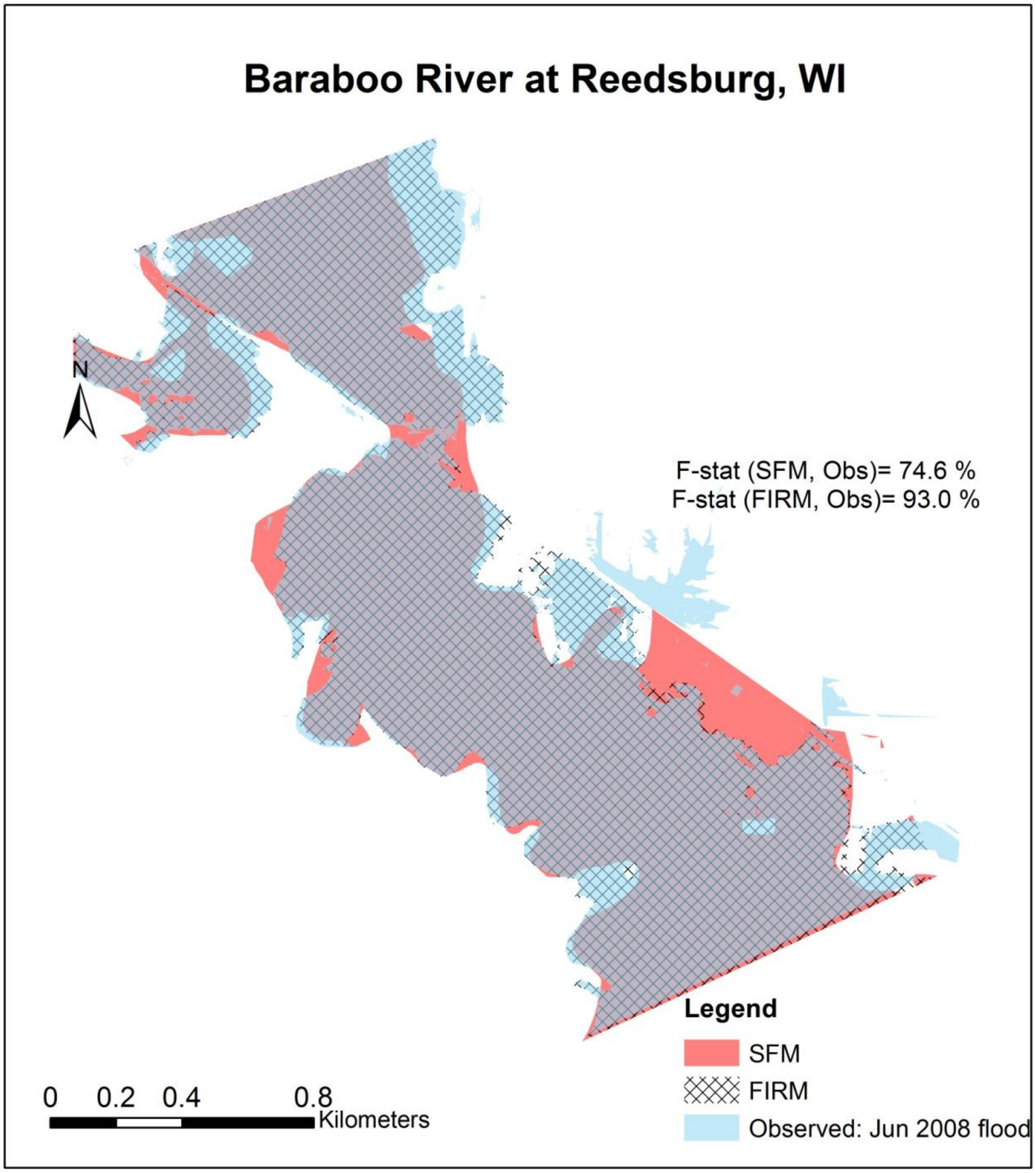

Baraboo River at Reedsburg, WI
N
F-stat (SFM, Obs)= 74.6 %
F-stat (FIRM, Obs)= 93.0 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.2 0.4 0.8
Kilometers

Figure C.30

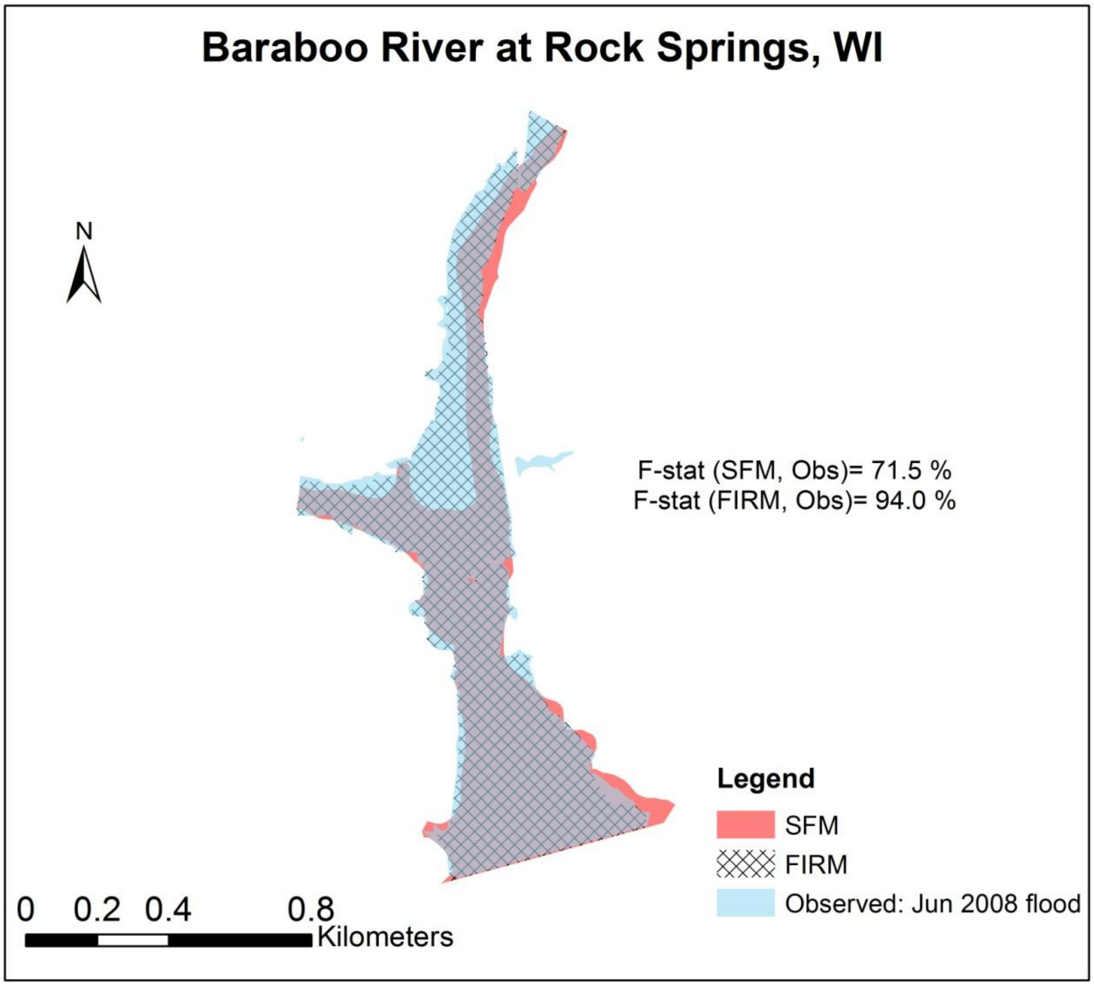

Baraboo River at Rock Springs, WI
N
F-stat (SFM, Obs)= 71.5 %
F-stat (FIRM, Obs)= 94.0 %
Legend
SFM
FIRM
Observed: Jun 2008 flood
0 0.2 0.4 0.8
Kilometers

Figure C.31

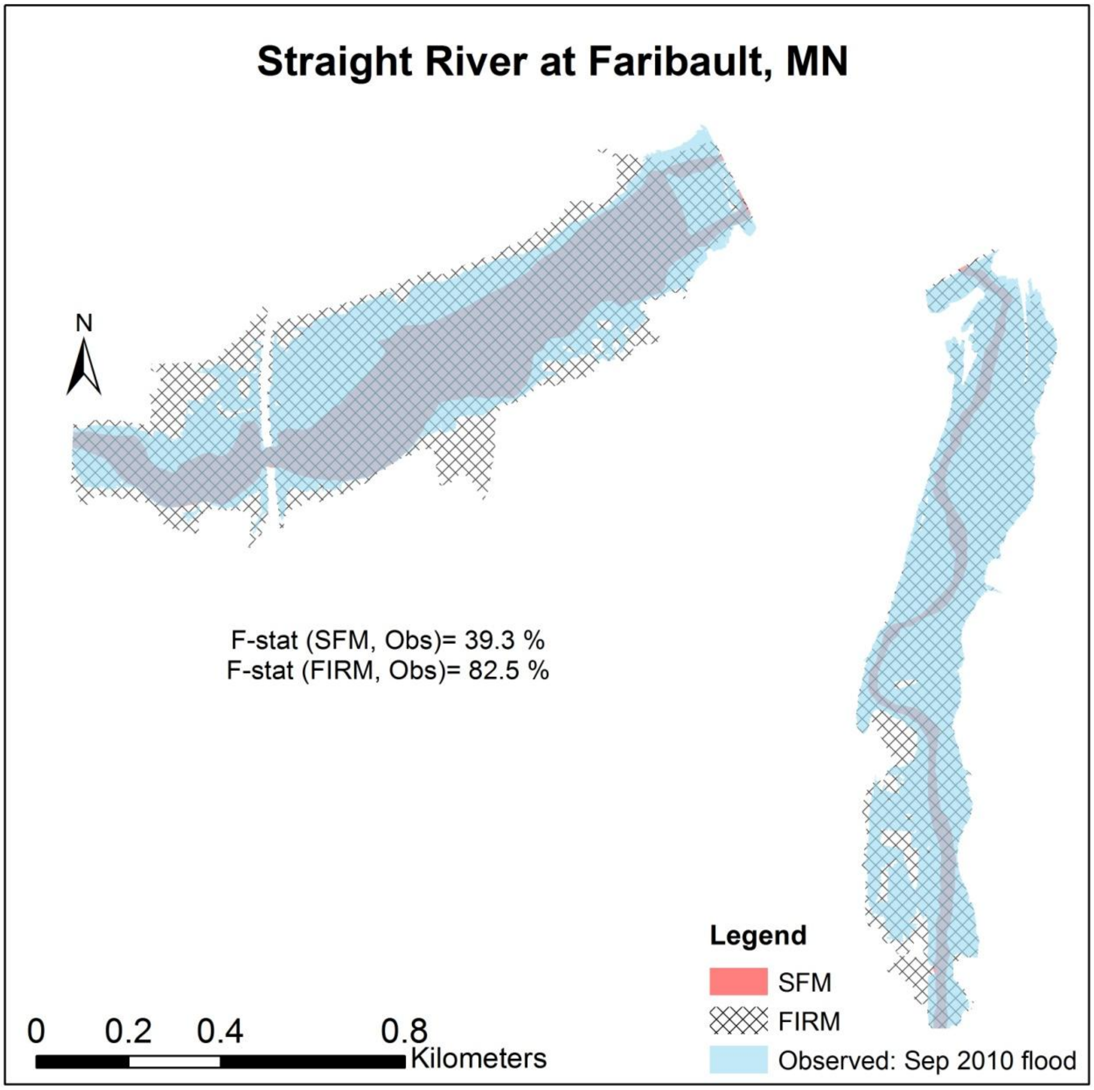

Straight River at Faribault, MN
N
F-stat (SFM, Obs)= 39.3 %
F-stat (FIRM, Obs)= 82.5 %
Legend
SFM
FIRM
Observed: Sep 2010 flood
0 0.2 0.4 0.8
Kilometers

Figure C.32

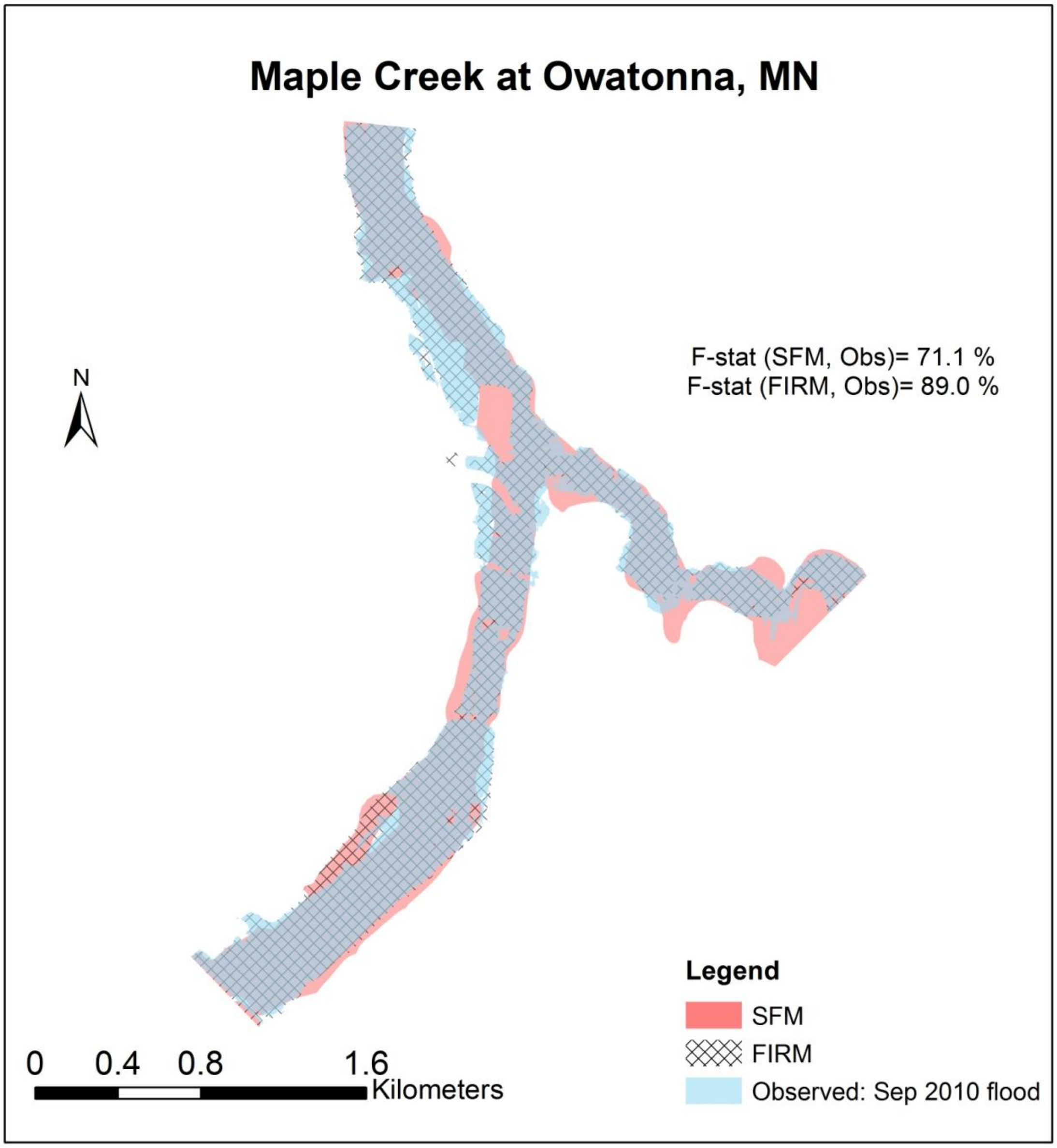
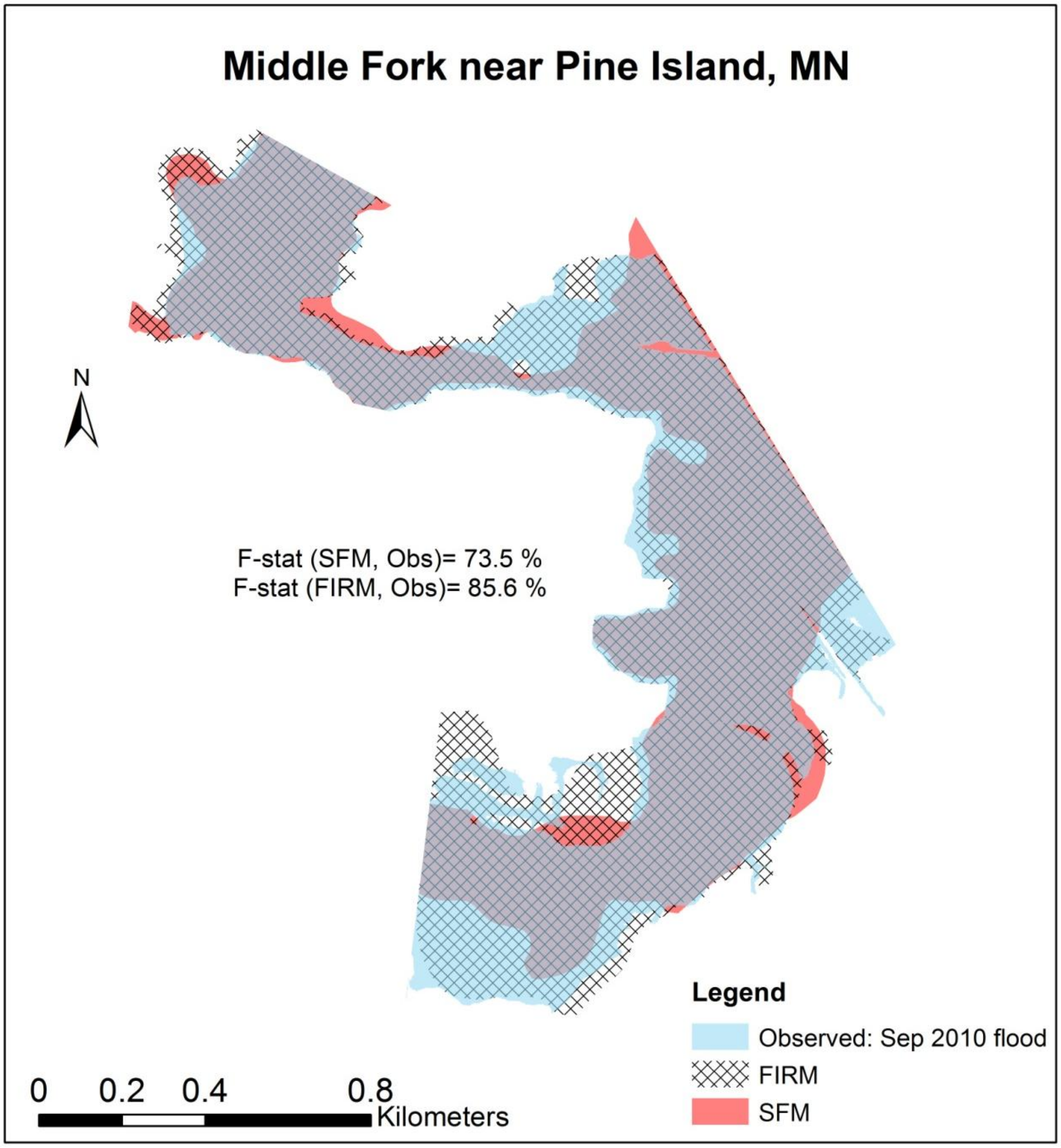

Maple Creek at Owatonna, MN
F-stat (SFM, Obs)= 71.1 %
F-stat (FIRM, Obs)= 89.0 %
N
0
0.4
0.8
1.6
Kilometers
Legend
SFM
FIRM
Observed: Sep 2010 flood

Figure C.33



Middle Fork near Pine Island, MN
N
F-stat (SFM, Obs)= 73.5 %
F-stat (FIRM, Obs)= 85.6 %
Legend
Observed: Sep 2010 flood
FIRM
SFM
0
0.2
0.4
0.8
Kilometers


Figure C.34

Appendix D Floodplain maps along lower order creeks

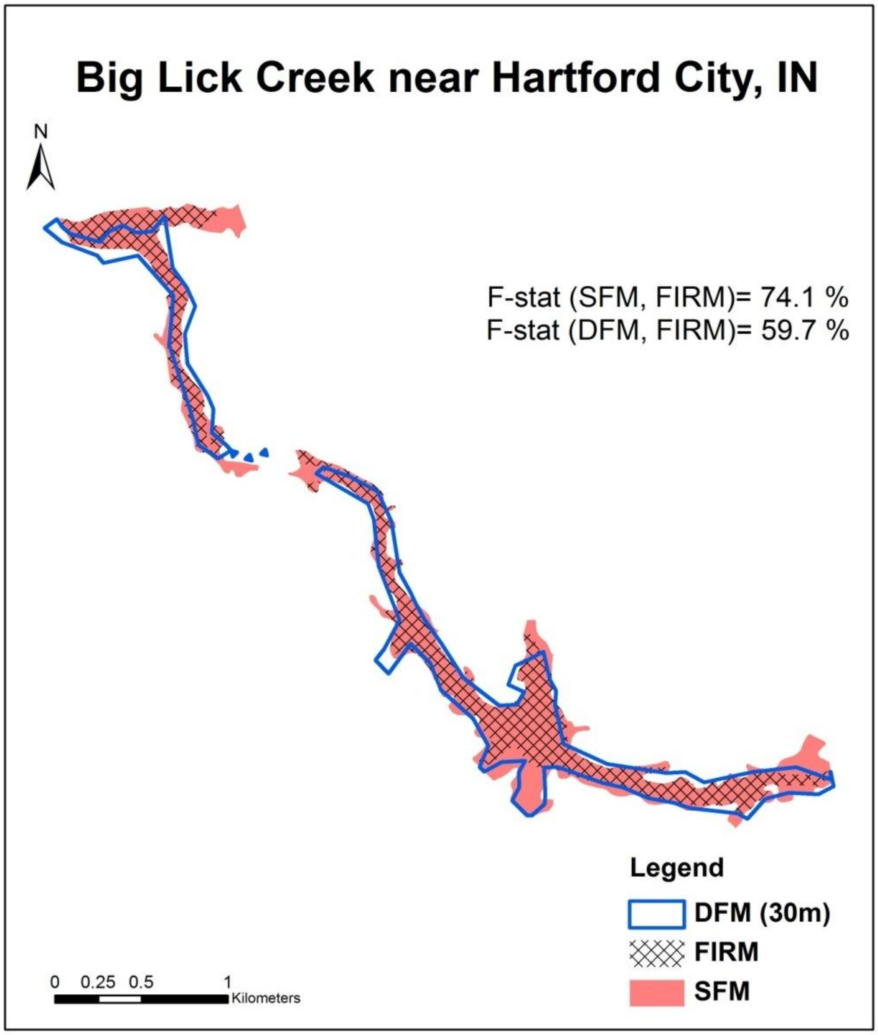



Figure D.1

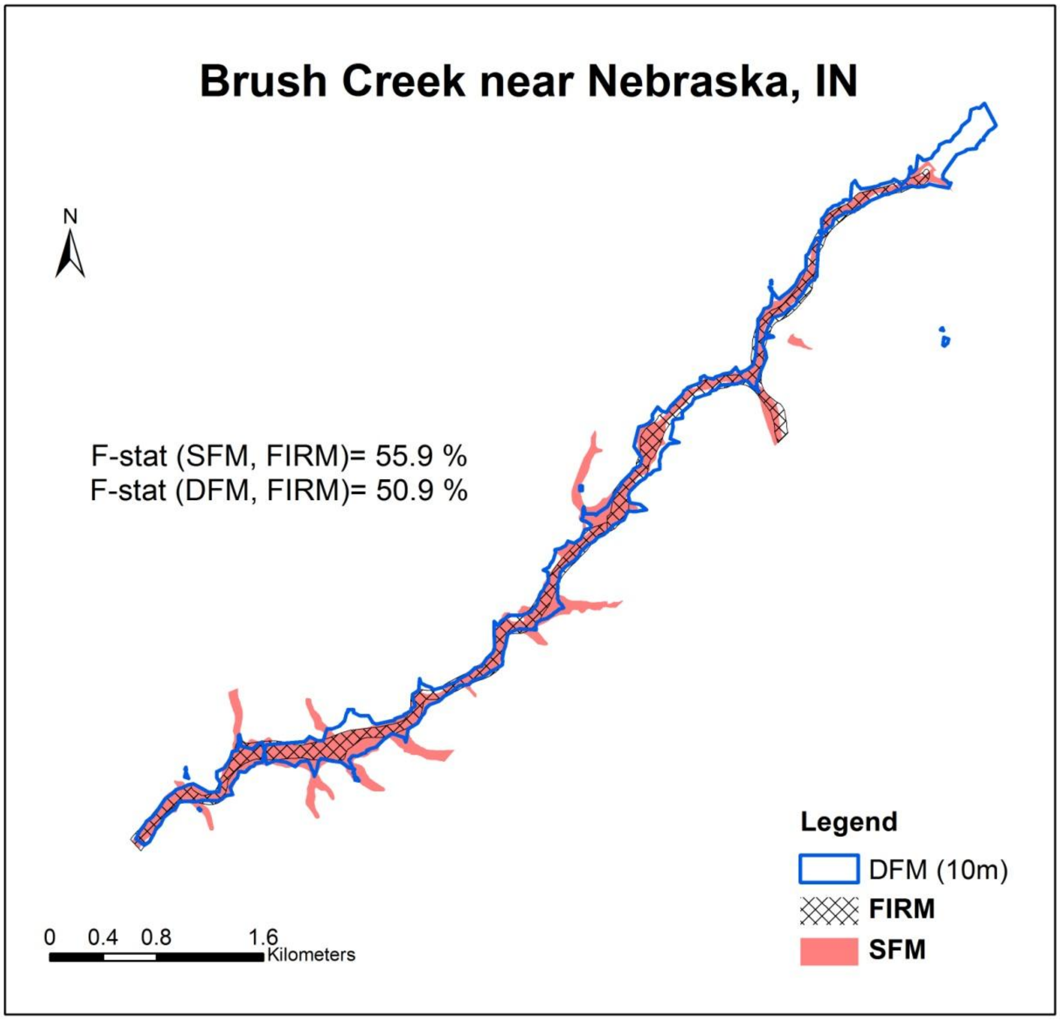

Brush Creek near Nebraska, IN
N
F-stat (SFM, FIRM)= 55.9 %
F-stat (DFM, FIRM)= 50.9 %
Legend
DFM (10m)
FIRM
SFM
0 0.4 0.8 1.6
Kilometers

Figure D.2

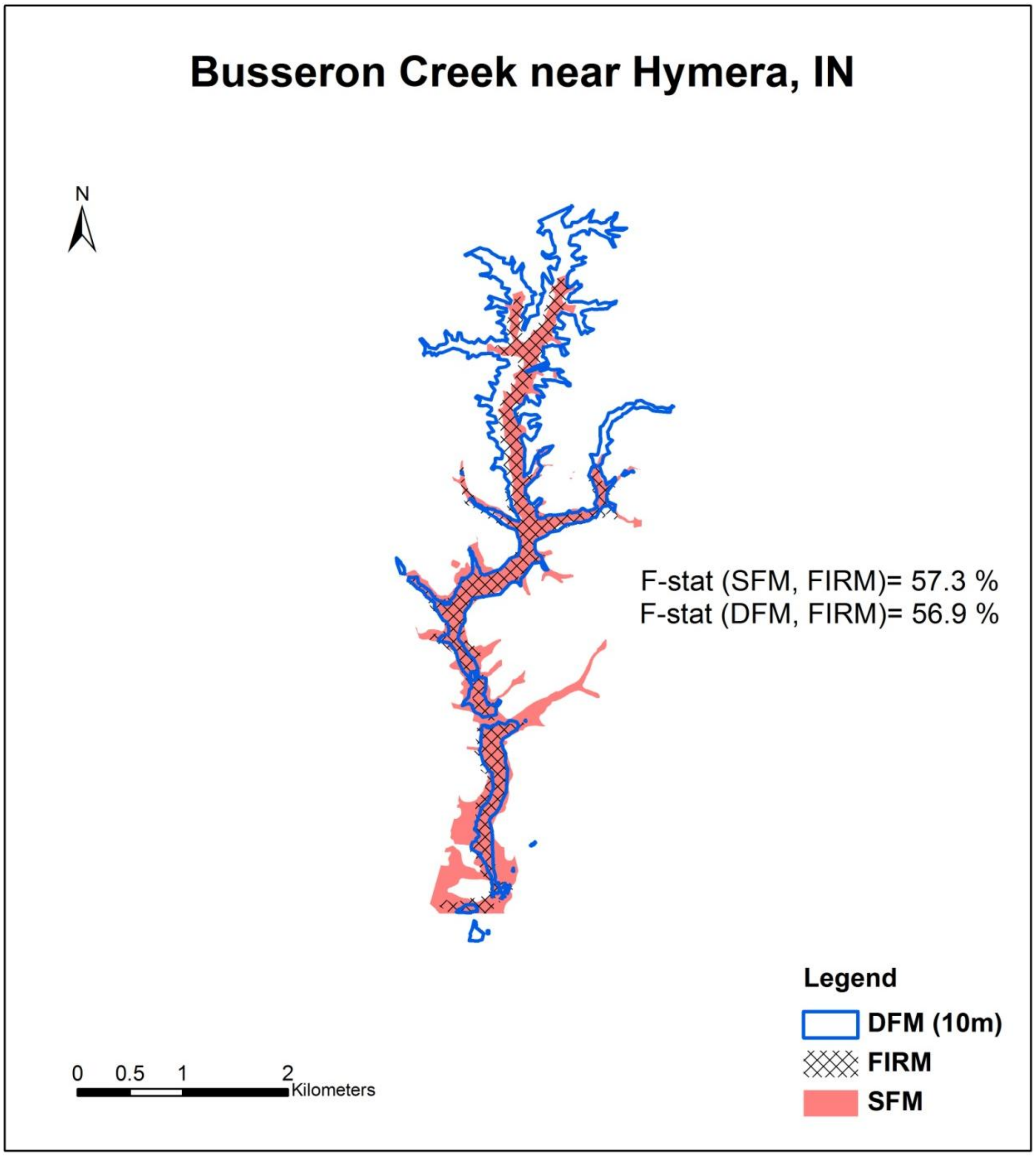

Busseron Creek near Hymera, IN
N
F-stat (SFM, FIRM)= 57.3 %
F-stat (DFM, FIRM)= 56.9 %
Legend
DFM (10m)
FIRM
SFM
0 0.5 1 2
Kilometers

Figure D.3

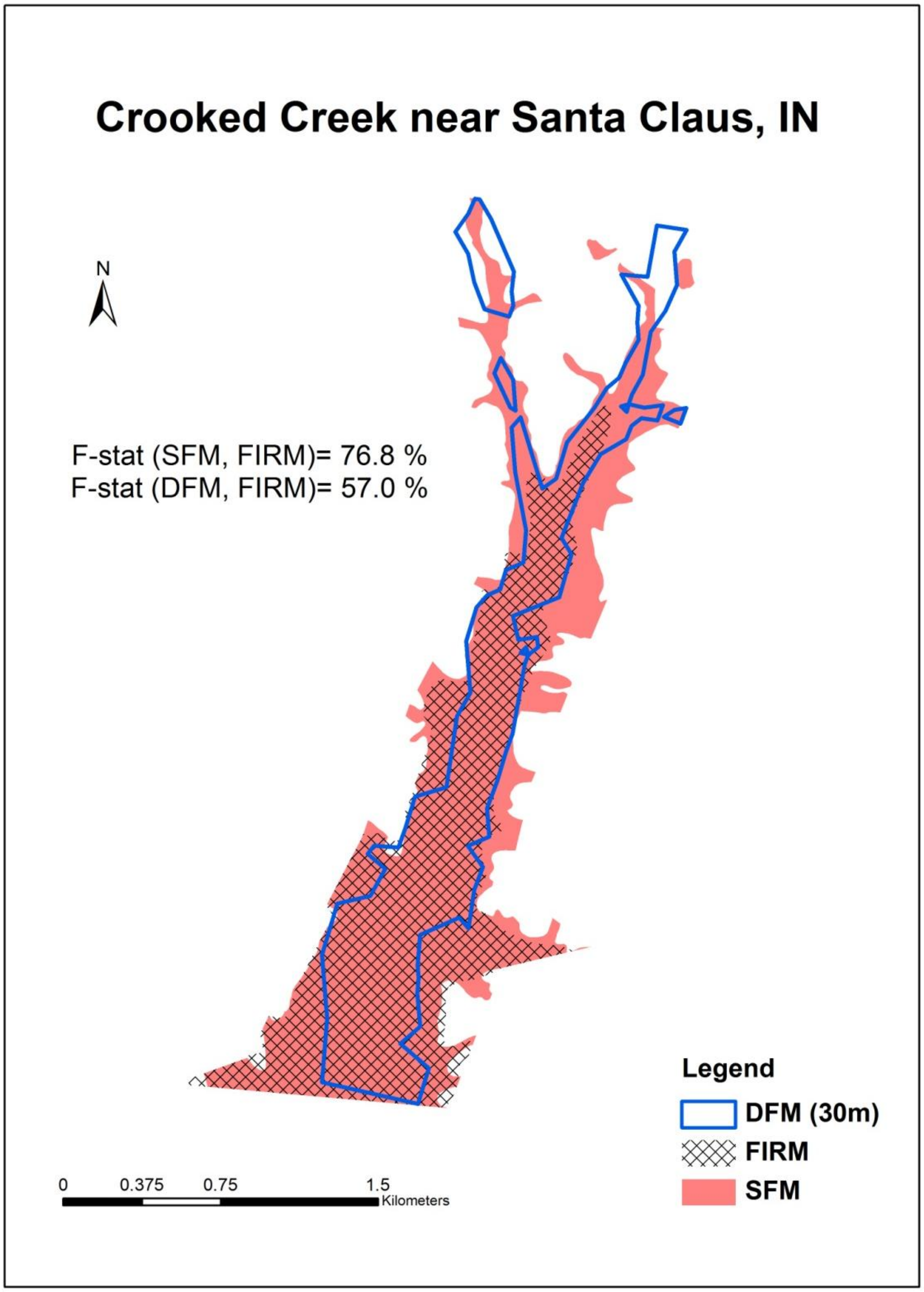

Crooked Creek near Santa Claus, IN
N
F-stat (SFM, FIRM)= 76.8 %
F-stat (DFM, FIRM)= 57.0 %
Legend
DFM (30m)
FIRM
SFM
0
0.375
0.75
1.5
Kilometers

Figure D.4

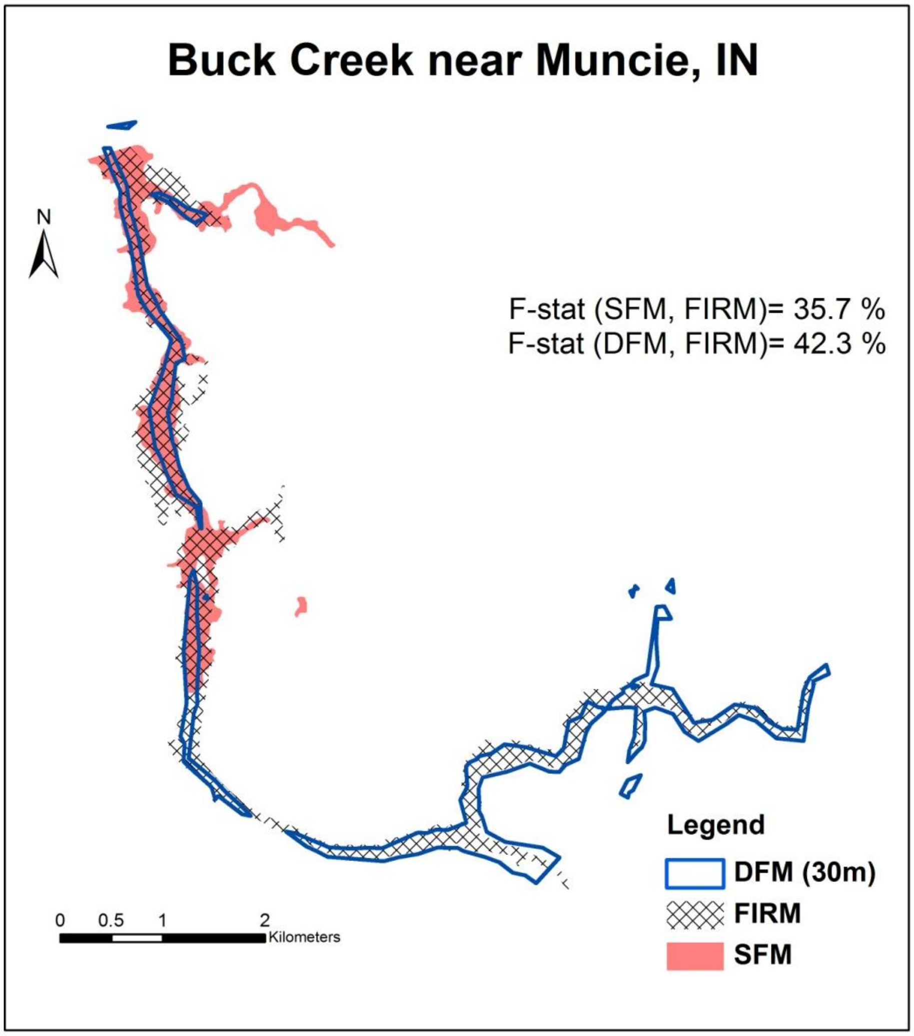
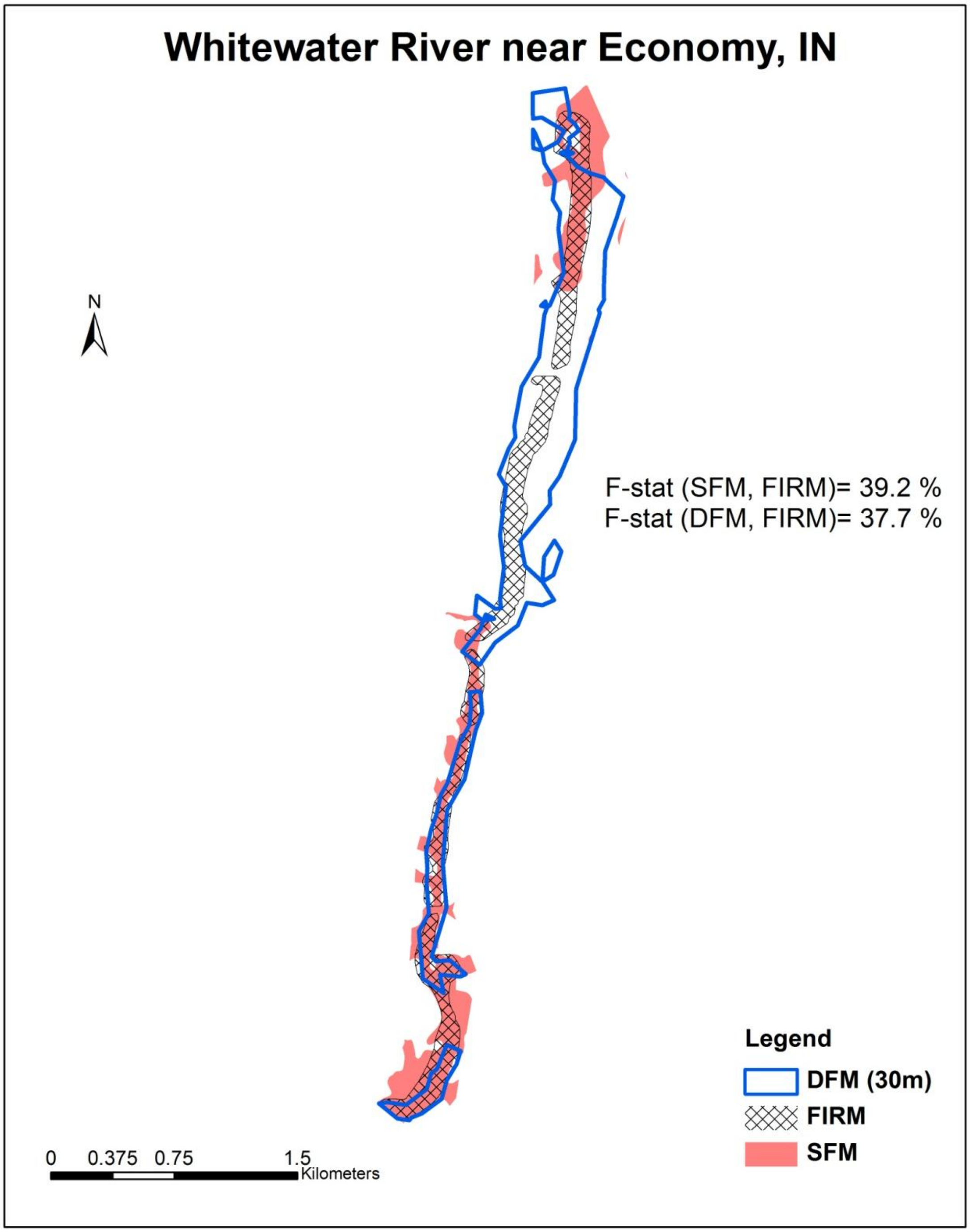

Buck Creek near Muncie, IN
N
F-stat (SFM, FIRM)= 35.7 %
F-stat (DFM, FIRM)= 42.3 %
Legend
DFM (30m)
FIRM
SFM
0 0.5 1 2
Kilometers

Figure D.5



Whitewater River near Economy, IN
N
F-stat (SFM, FIRM)= 39.2 %
F-stat (DFM, FIRM)= 37.7 %
Legend
DFM (30m)
FIRM
SFM
0 0.375 0.75 1.5
Kilometers


Figure D.6

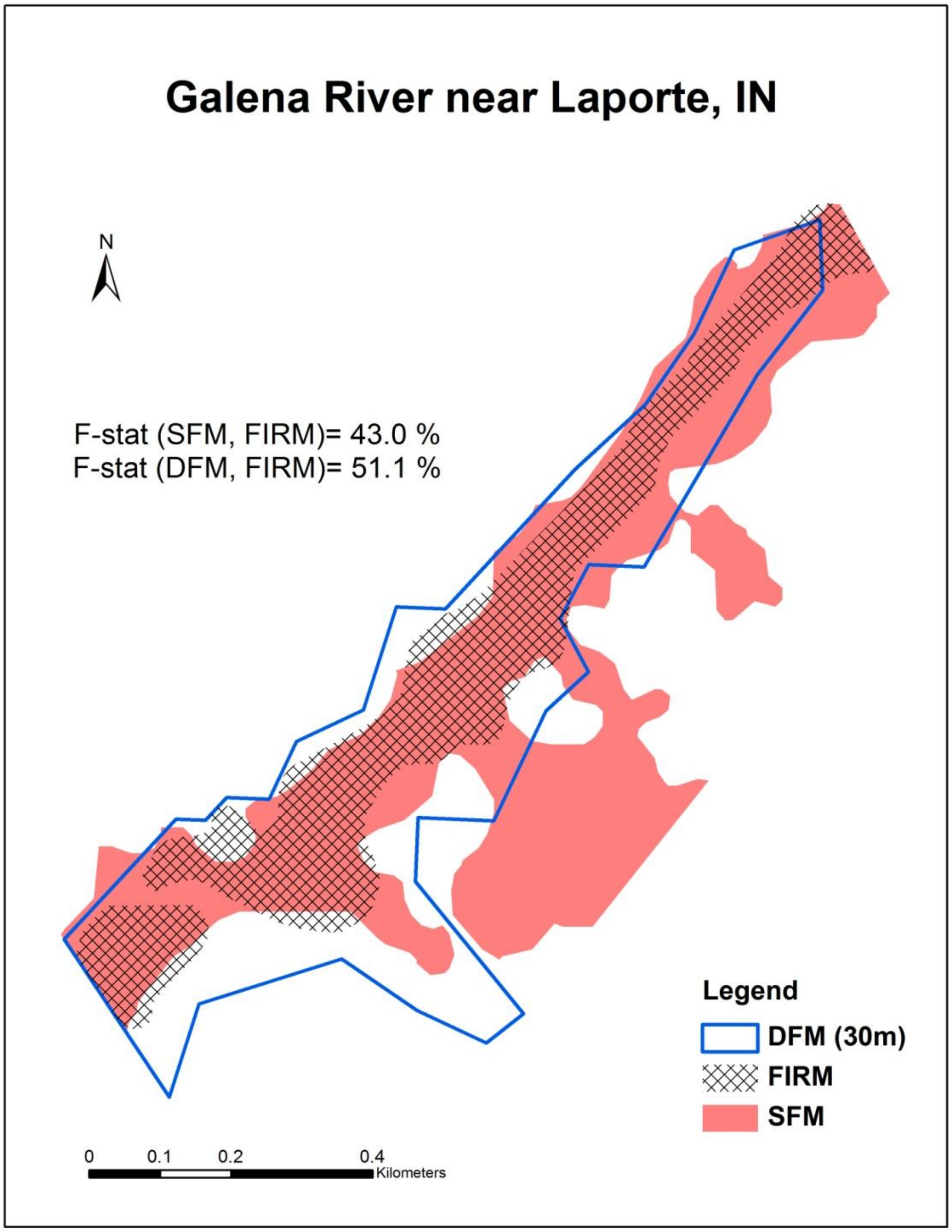

Galena River near Laporte, IN
N
F-stat (SFM, FIRM)= 43.0 %
F-stat (DFM, FIRM)= 51.1 %
Legend
DFM (30m)
FIRM
SFM
0 0.1 0.2 0.4
Kilometers

Figure D.7

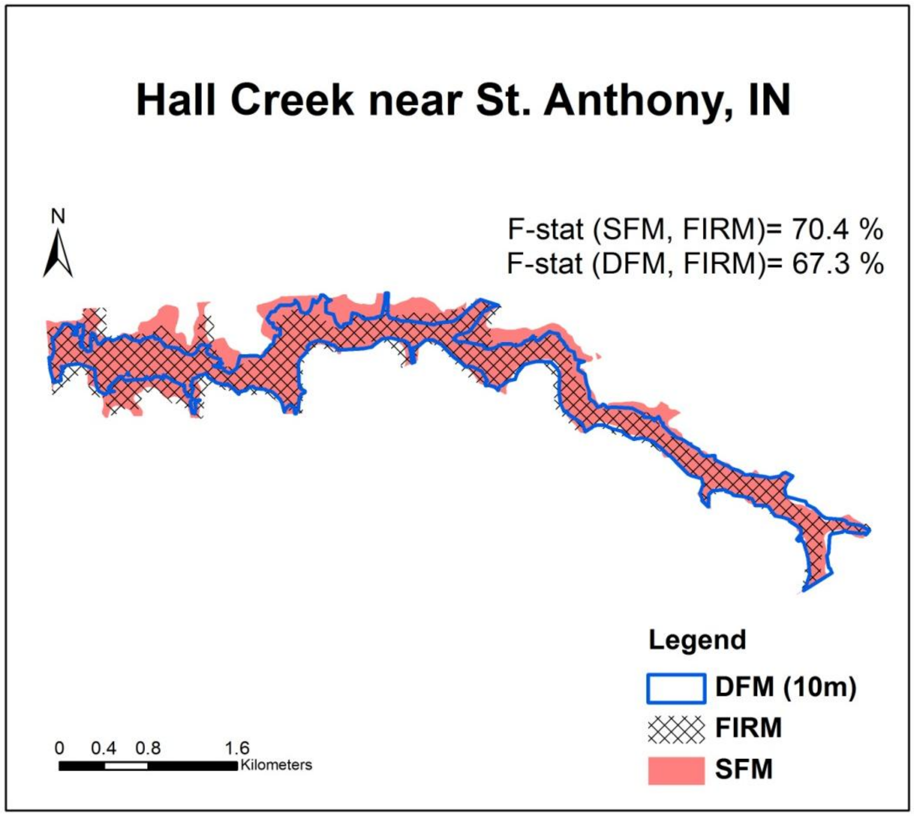
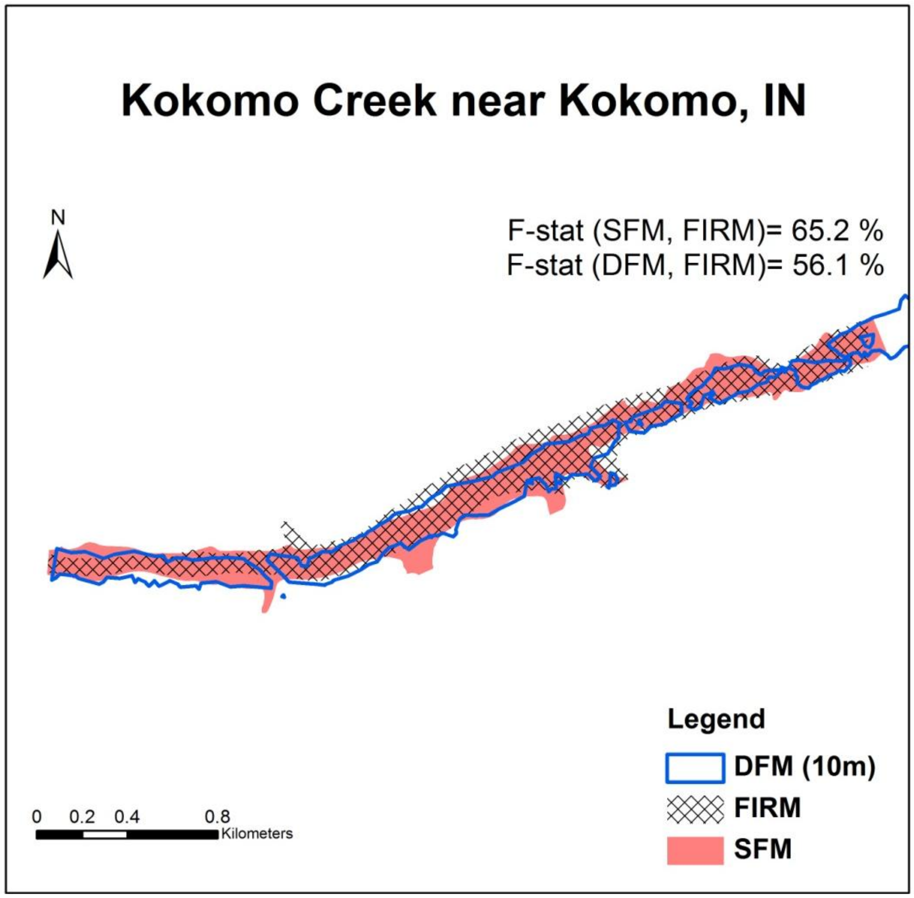

Hall Creek near St. Anthony, IN
N
F-stat (SFM, FIRM)= 70.4 %
F-stat (DFM, FIRM)= 67.3 %
Legend
DFM (10m)
FIRM
SFM
0 0.4 0.8 1.6
Kilometers

Figure D.8



Kokomo Creek near Kokomo, IN
N
F-stat (SFM, FIRM)= 65.2 %
F-stat (DFM, FIRM)= 56.1 %
Legend
DFM (10m)
FIRM
SFM
0 0.2 0.4 0.8
Kilometers


Figure D.9

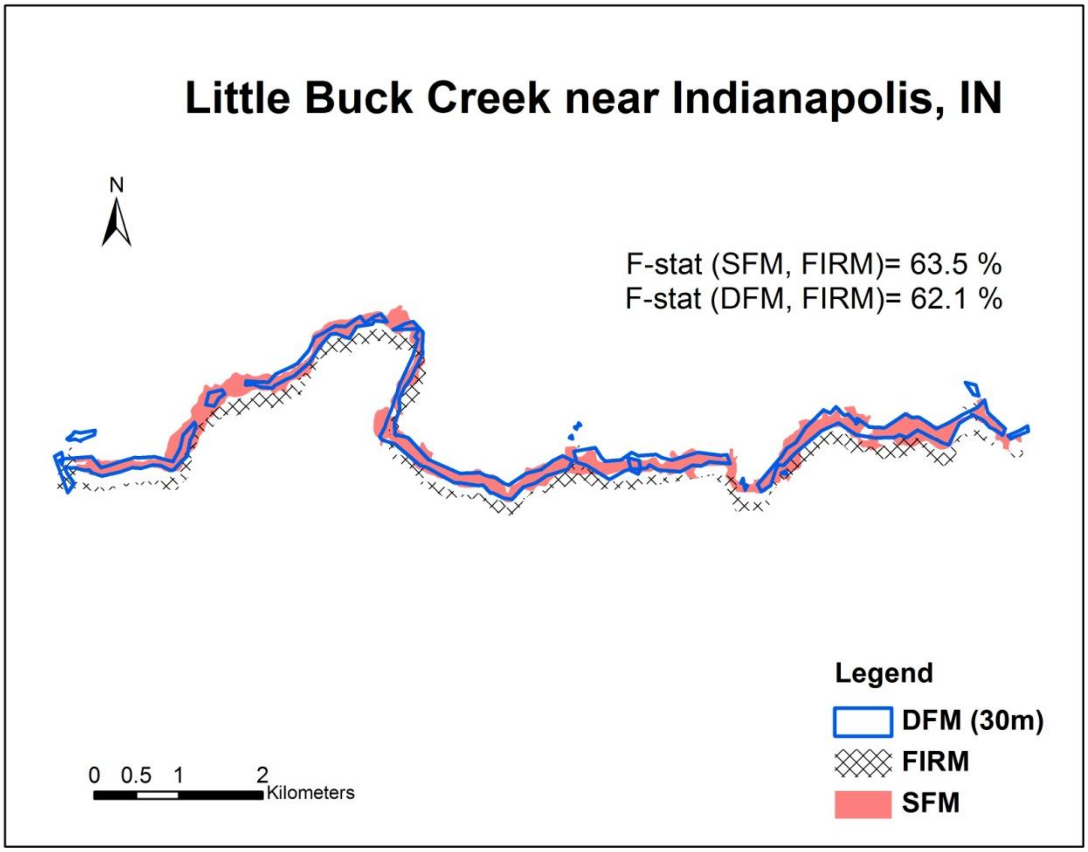

Little Buck Creek near Indianapolis, IN
N
F-stat (SFM, FIRM)= 63.5 %
F-stat (DFM, FIRM)= 62.1 %
Legend
DFM (30m)
FIRM
SFM
0 0.5 1 2
Kilometers

Figure D.10

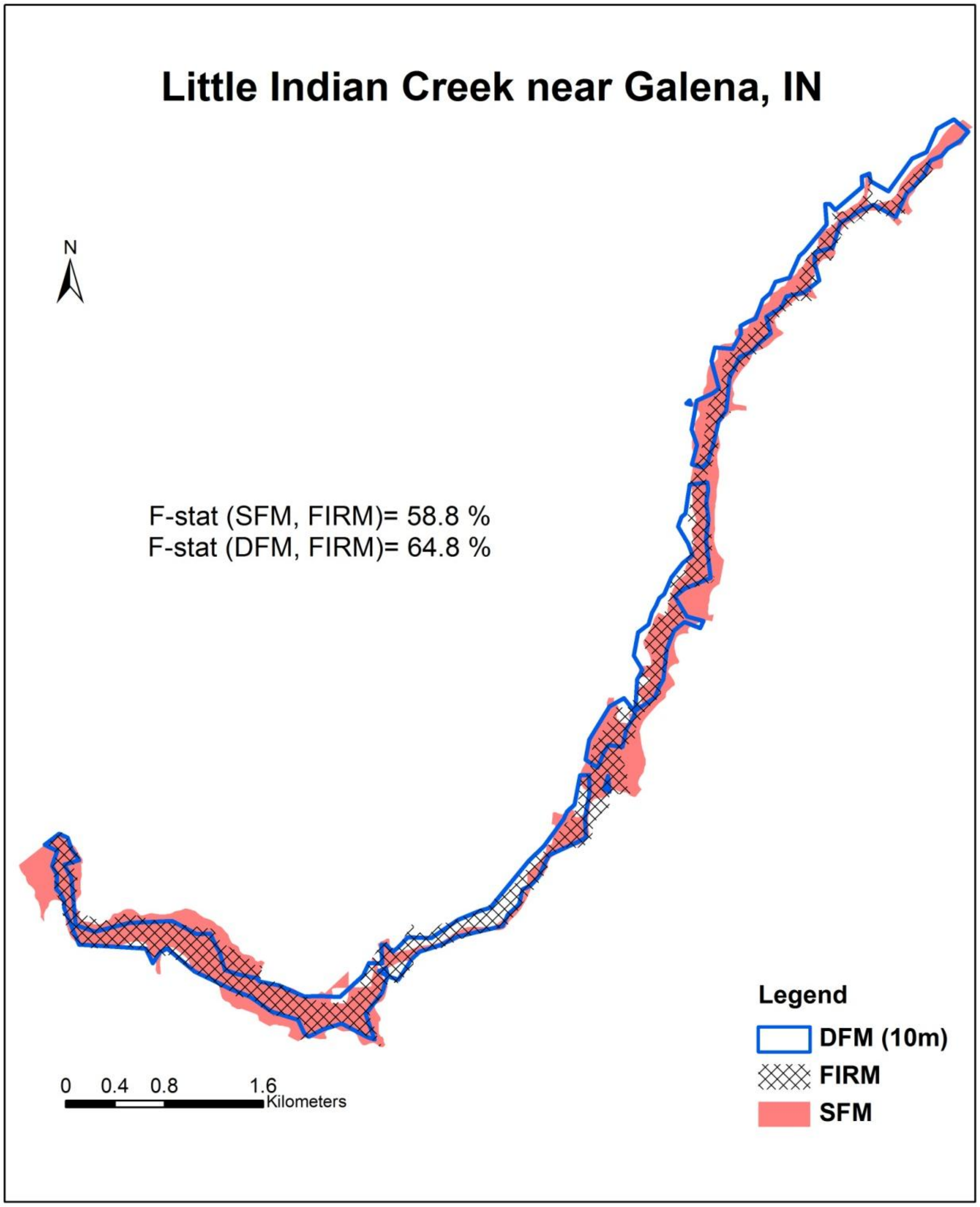

Little Indian Creek near Galena, IN
N
F-stat (SFM, FIRM)= 58.8 %
F-stat (DFM, FIRM)= 64.8 %
Legend
DFM (10m)
FIRM
SFM
0 0.4 0.8 1.6
Kilometers

Figure D.11

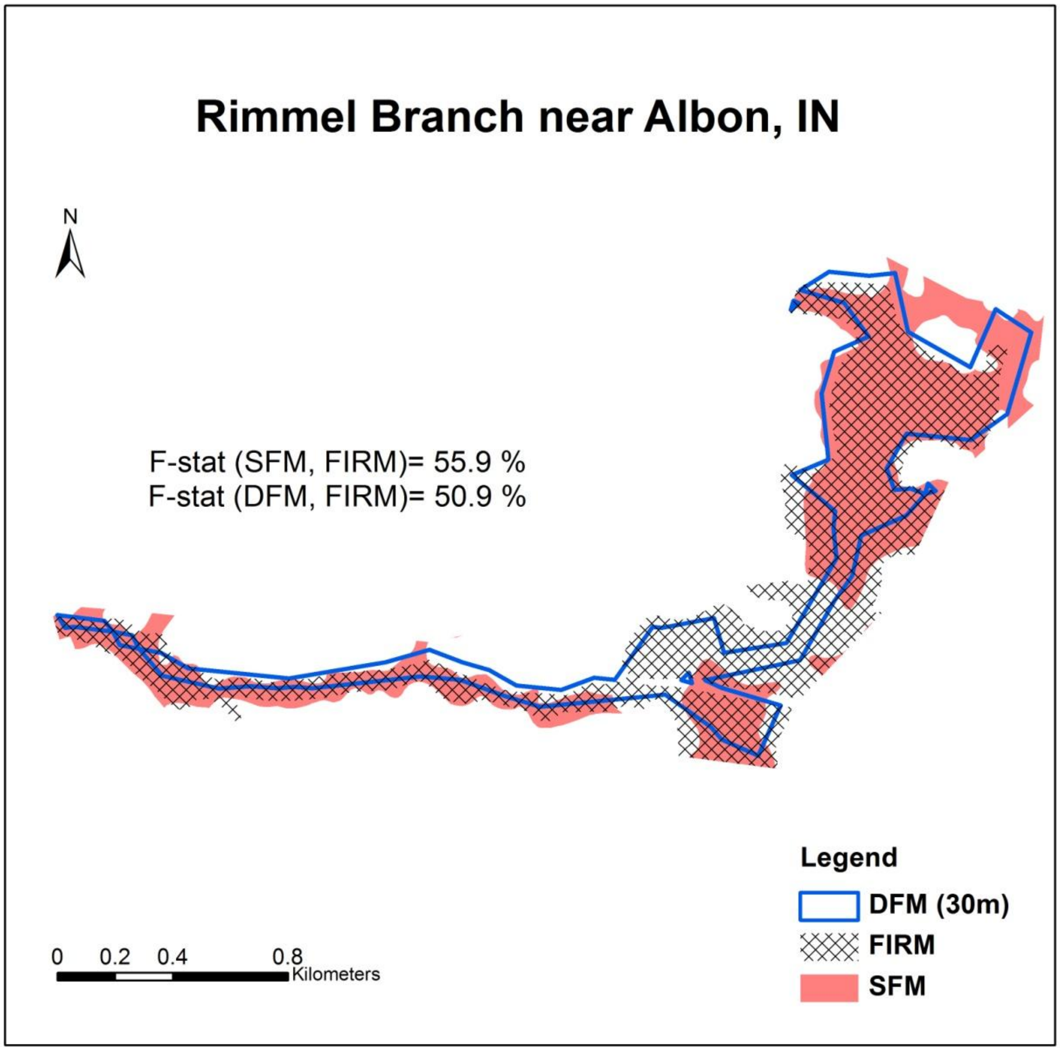
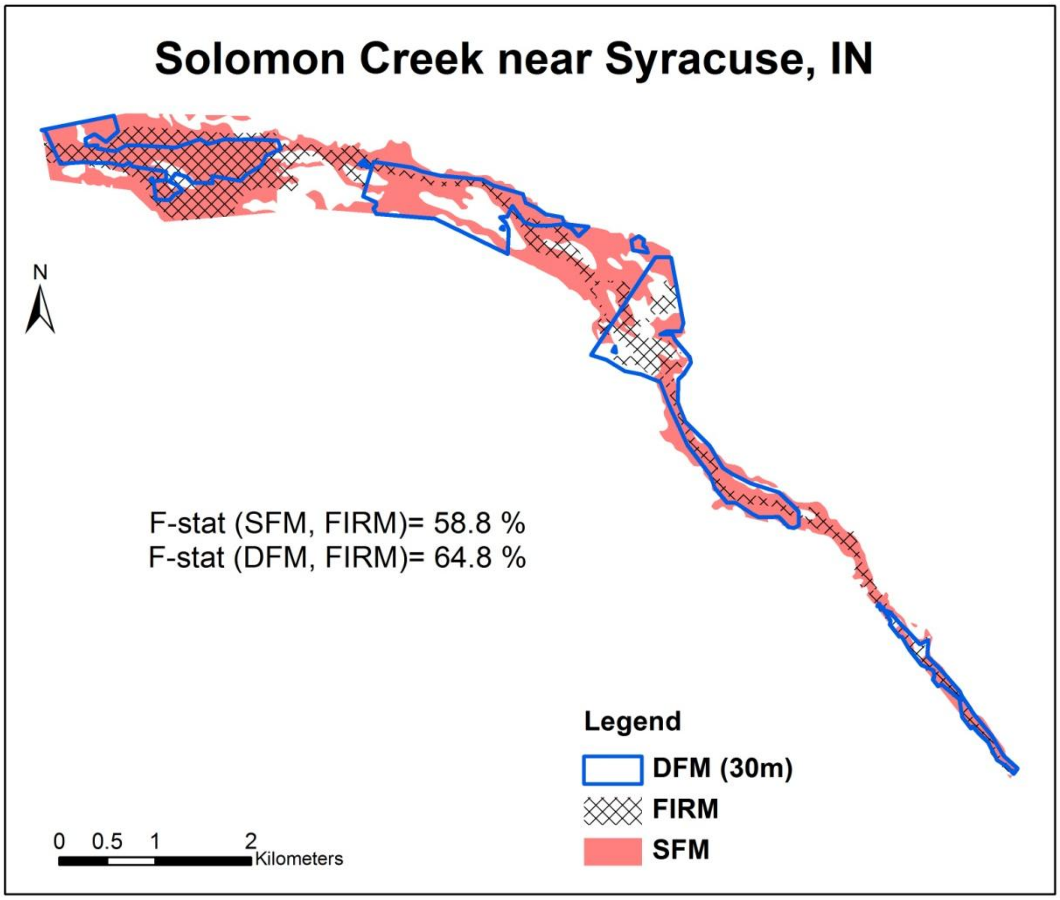

Rimmel Branch near Albon, IN
N
F-stat (SFM, FIRM)= 55.9 %
F-stat (DFM, FIRM)= 50.9 %
Legend
DFM (30m)
FIRM
SFM
0 0.2 0.4 0.8
Kilometers

Figure D.12



Solomon Creek near Syracuse, IN
N
F-stat (SFM, FIRM)= 58.8 %
F-stat (DFM, FIRM)= 64.8 %
Legend
DFM (30m)
FIRM
SFM
0 0.5 1 2
Kilometers


Figure D.13

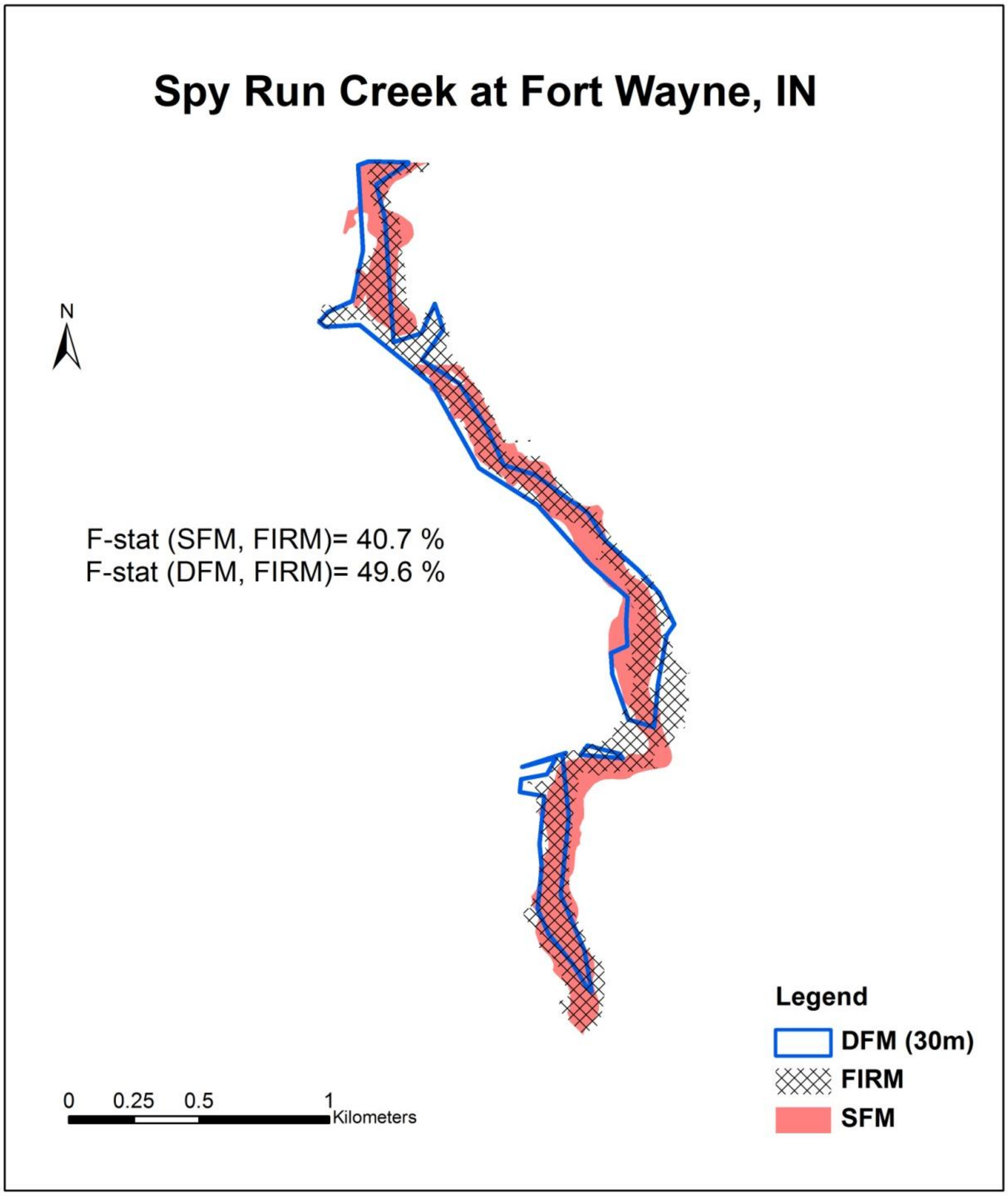

Spy Run Creek at Fort Wayne, IN
N
F-stat (SFM, FIRM)= 40.7 %
F-stat (DFM, FIRM)= 49.6 %
0 0.25 0.5 1
Kilometers
Legend
DFM (30m)
FIRM
SFM

Figure D.14

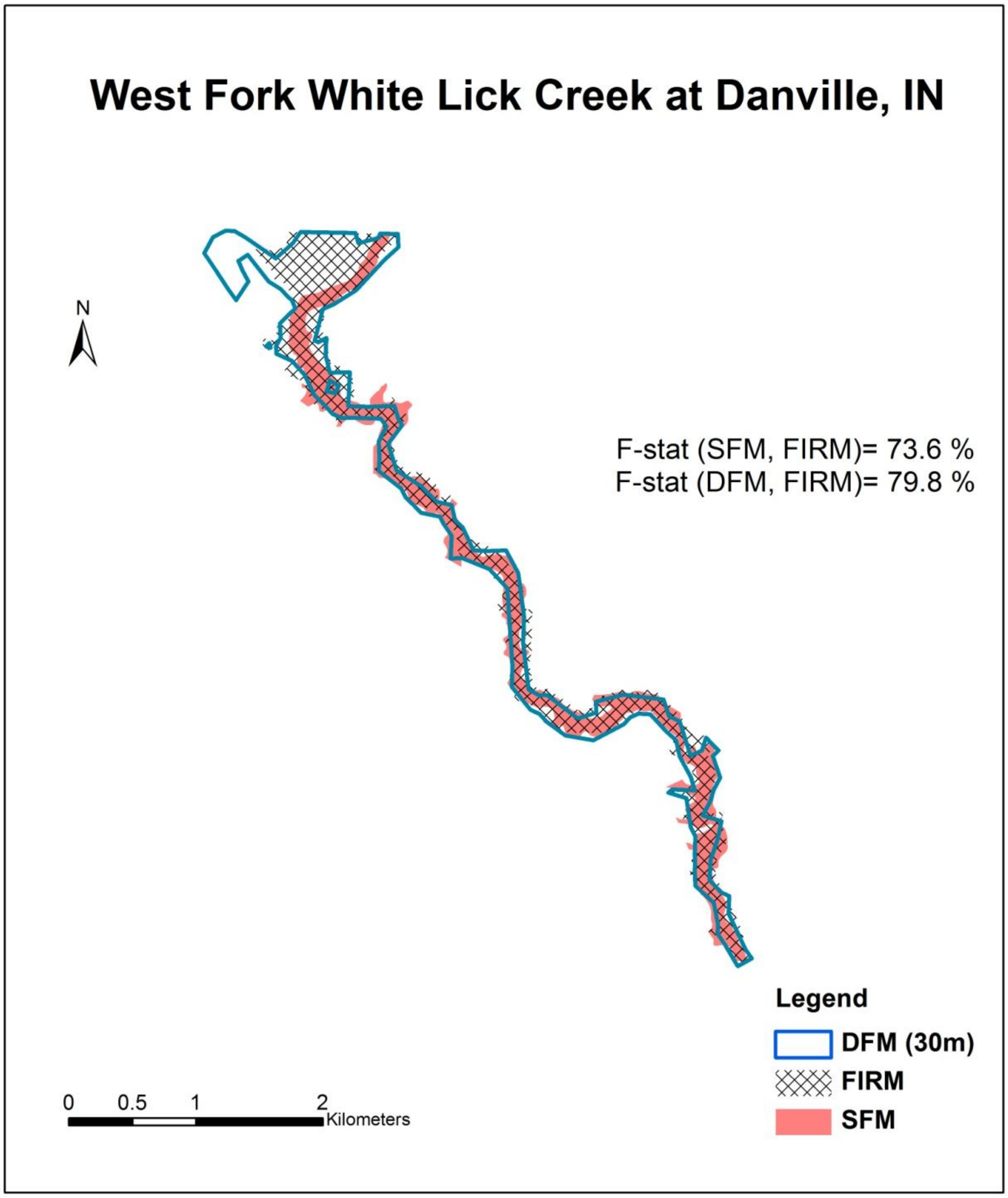

West Fork White Lick Creek at Danville, IN
N
F-stat (SFM, FIRM)= 73.6 %
F-stat (DFM, FIRM)= 79.8 %
Legend
DFM (30m)
FIRM
SFM
0 0.5 1 2
Kilometers

Figure D.15